

STOPPING AIR POLLUTION AT ITS SOURCE



CAP

Clean Air Program

CAP
Clean Air Program
Draft Regulation
APPENDICES 8 - 11



August 1990

PREFACE

In November 1987, the Ministry of the Environment released a discussion paper on a new Clean Air Program for Ontario entitled "Stopping Air Pollution at its Source." During a 90-day comment period a series of public and special interest group meetings were held throughout the Province and wide-ranging written submissions were made to the Minister.

The Draft Regulation of the Clean Air Program contains an overview document accompanied by several appendices which describe procedures and protocols in detail. The appendices are referenced and described below and in each volume. Copies of the documents can be obtained separately or as a package from:

Environment Ontario
Public Information Centre
135 St. Clair Avenue West
Toronto, Ontario
M4V 1P5

Telephone Number (416) 323-4321

These materials will be subject to a 180-day review period during which interested parties are invited to make submissions to the Minister. Following the review period the Ministry will take account of these comments and produce a revised Draft Regulation prior to filing a final Draft Regulation with the Registrar of Regulations.

Summary of CAP Documentation

The Clean Air Program Draft Regulation outlines the Ontario Ministry of the Environment's proposals for regulating stationary air emission sources in the Province. The contents of the Draft Regulation are presented in an overview document and three volumes of appendices. An additional volume summarizes the comments received by the Ministry on its 1987 Discussion Paper - "Stopping Air Pollution At Its Source." In order to assist in the reading of the documents the following summary of the contents of the various volumes is presented:

Draft Regulation Overview:

In this volume the key elements of the Clean Air Program are identified, and the way in which the Ministry is proposing that they should be integrated into a new regulatory package is specified.

Responses to Public Comments:

Comments received at public meetings, meetings with special interest groups, an open workshop, and in submissions to the Minister as a result of the Discussion Paper are summarized, and references are provided as to how and where the comments have been incorporated into the Draft Regulation or reasons are supplied as to why this has not been possible.

Appendices 1 and 2

Appendix 1 - **DEFINITIONS**

Technical terms used in the overview document and in the other appendices are defined to facilitate the interpretation of these documents.

Appendix 2 - **SOURCE REGISTRATION**

Appendix 2-1 - **SOURCE REGISTRATION RATIONALE**

The purpose and intent of the proposed source registration scheme are identified.

Appendix 2-2 - **SOURCE REGISTRATION LEGISLATION**

The anticipated scope of the proposed source registration scheme is outlined. The applicability of source registration, and the requirements on owners and operators, including thresholds, the proposed treatment of mixtures and trade names, and proposed exemptions are identified.

Appendix 2-3 - **LISTS OF CHEMICAL SUBSTANCES FOR SOURCE REGISTRATION**

The list of chemicals which owners or operators will be required to consider when filing a source registration statement is provided. This list is presented (1) in alphabetical order, (2) by CAS number order with synonyms, and (3) by synonyms in alphabetical order.

Appendix 2-4 - **CANADIAN STANDARD INDUSTRIAL CLASSIFICATION CODES**

A listing of the Canadian Standard Industrial Classification Codes accompanies the Lists of Chemical Substances for Source Registration which it is proposed should be dealt with in the initial phase, the second phase and the third phase.

Appendix 2-5 - **SAMPLE REGISTRATION FORM**

A sample registration form is provided.

Appendix 2-6 - **SAMPLE INSTRUCTIONS**

A sample of the instructions (from U.S. E.P.A. SARA Title III Section 313) is supplied.

Appendix 2-7 - **SAMPLE EMISSION CROSS-REFERENCE**

A sample of the Emission Cross-Reference and Section 313 Final Rule (which includes a sample method for estimating releases) is provided.

Appendices 3-7

Appendix 3 - **IMPLEMENTATION OF THE CLEAN AIR PROGRAM**

The manner in which it is proposed to implement the Clean Air Program is provided.

Appendix 4 - **APPROVALS**

The details of the proposed approvals mechanisms under the Clean Air Program are provided.

Appendix 4-1 - **APPROVALS PROCESS**

The proposed requirements of the Ministry's air approvals process, under which certificates of approval to construct and operate will be issued, are specified together with basic information requirements for the process, and the manner in which it is proposed the process should operate.

Appendix 4-2 - **GENERIC CERTIFICATES OF APPROVAL**

The proposals to handle the granting of certificates of approval to sources which have minor impact on the environment, and have common characteristics which permit generic or class control limitations to be employed, are itemized. An example based on US state regulations for dry cleaning establishments is appended.

Appendix 4-3 - **EXPERIMENTAL FACILITIES**

Proposed measures for handling pilot plants, laboratories and prototypes are identified.

Appendix 5 - **SMALL AND SPECIAL SOURCES**

The Ministry's proposals for handling the approval of small and special sources are described.

Appendix 5-1 - **SMALL SOURCE DESIGNATION LIMITS**

The Ministry's suggested methodology for defining small sources, exempt from control technology requirements, is provided, accompanied by a list of suggested small source designation limits for chemicals included in the source registration process.

Appendix 5-2 - **CODES OF PRACTICE - CONCEPTUAL OUTLINE**

Codes of Practice are suggested as a mechanism for handling the regulation of certain types of sources. These include sources not amenable to conventional control technologies, defined as necessary or unavoidable and/or conducted infrequently or for short time periods at a particular location. The general conditions which will be included in codes of practice and a sample for open burning are provided.

Appendix 6 - **CONTAMINANT CLASSIFICATION PROCESS AND AIR QUALITY STANDARDS**

The methodologies which are proposed for the contaminant classification process and the setting of air quality standards are discussed.

Appendix 6-1 - **OVERVIEW: CLASSIFICATION, REGULATORY STRATEGIES AND AIR QUALITY STANDARDS**

The role of classification and air quality standards in the Clean Air Program; definition of a target list of chemicals; the classification methods which will be used; features of the "interim classification" system, including a so-called "public participation in classification process"; and the general characteristics of the proposed system for defining regulatory strategies, criteria and standards are summarized.

Appendix 6-2 - **THE CLEAN AIR PROGRAM (CAP) GENERIC CLASSIFICATION PROCESS**

The types of information which will be considered in the process of classifying contaminants are identified.

Appendix 6-3 - **INTERNAL MINISTRY OF THE ENVIRONMENT CHEMICAL LEVEL-OF-CONCERN CLASSIFICATION PROCESS**

Details of the proposed Ministry of the Environment process for classifying contaminants are supplied. Three methods are identified: development of (1) "detailed" or (2) "preliminary" dossiers together with the use of the MOE detailed scoring system; (3) and the use of various jurisdictional and property information.

Appendix 6-4 - **LIST OF CONTAMINANTS CLASSIFIED ON THE BASIS OF LEVEL-OF-CONCERN**

Included in this Appendix are an "interim" classification of contaminants listed as emissions in certificates of approval over recent years, and priority chemicals believed to be in use in Ontario which have been identified under the Canadian Environmental Protection Act or by other recognized jurisdictions as being of concern.

Appendix 6-5 - **PART 1: PUBLIC PARTICIPATION IN THE CLASSIFICATION PROCESS**

The process whereby the public, industry, and interested parties will be able to contribute to the classification of contaminants, is detailed.

Appendix 6-5 - **PART 2: CHEMICAL DOSSIERS**

Details of the requirements concerning the submission chemical dossiers are supplied, together with a manual describing the Chemical Evaluation Search and Retrieval System (CESARS) written by the Michigan Department of Natural Resources as part of a joint effort with the Province of Ontario.

Appendix 6-6 - **REGULATORY STRATEGIES: THE DECISION PROCESS**

A three-tier approach which the Ministry of the Environment is considering in order to produce air quality standards and chemical specific regulatory strategies is discussed.

Appendix 6-7 - **INTERIM AIR QUALITY STANDARDS**

The values which the Ministry is proposing to use in connection with the new modelling package in evaluating applications for certificates of approval are supplied. The lists are arranged according to the averaging period which will be used: 24 hour; 1 hour; 10 minute; irregular averaging times; and 1 year.

Appendix 7 - **EMISSION LIMITS AND APPROVALS**

The Ministry's proposed mechanisms for setting and listing emission limits for use in the certificate of approval process are provided.

Appendix 7-1 - **EMISSION LIMITS**

The emission limits for various processes which the Ministry is proposing should be appended to a final draft regulation and used in the certificate of approval process are discussed.

Appendix 7-2 - **GUIDELINE FOR DETERMINATION OF EMISSION LIMITS**

The policies and requirements of the Ontario Ministry of the Environment used in setting emission limits under the Clean Air Program are documented.

Appendix 7-3 - **THE EMISSION LIMIT-SETTING PROCESS**

The process for setting emission limits is outlined.

Appendix 7-4 - **REQUIREMENTS FOR UPSETS, START-UPS,
SHUTDOWNS AND BYPASSES**

The conditions under which by-passing of air pollution control systems are not permitted are identified.

Appendix 7-5 - **VISIBLE EMISSIONS**

The Ministry's proposals concerning visible emissions are provided together with U.S. E.P.A. Regulations on Standards of Performance for New Stationary Sources which will be used as a basis for proposed regulatory changes.

Appendix 7-6 - **PUBLIC CONSULTATION PROVISIONS**

Proposed avenues for public discussion of emission limit setting and the issuance of certificates of approval are identified.

Appendices 8-11

Appendix 8 - **AIR QUALITY MODELLING**

An overview of the dispersion modelling requirements associated with the certificate of approval process is provided, including the manner in which the modelling should be applied.

Appendix 8-1 - **A GENERAL USER'S GUIDE FOR SOURCE
ASSESSMENT**

Details of the requirements concerning modelling are supplied.

Appendix 8-2 - **DETAILED DESCRIPTION OF THE FULL MULTI-
SOURCE AIR QUALITY MODELLING TECHNIQUE
FOR CALCULATION OF LOCAL AIR
CONCENTRATIONS**

The modelling package which the Ministry is proposing is described in detail complete with equations.

Appendix 8-3 - **MODELLING SCHEDULE - METHODOLOGY FOR THE DETERMINATION OF METEOROLOGICAL PARAMETERS REQUIRED FOR THE FULL AIR QUALITY MODEL CALCULATIONS.**

The process for determining the meteorological inputs to the dispersion models is described.

Appendix 8-4 - **A USER'S GUIDE TO THE AIR QUALITY MODELLING SOFTWARE**

A guide is provided to facilitate the running of the computer programs associated with the dispersion modelling package.

Appendix 8-5 - **SUPPLEMENTARY CONTROL PROGRAMS**

The conditions under which the Ministry is proposing that supplementary control programs should be utilized under CAP are identified.

Appendix 9 - **SOURCE TESTING**

The general provisions which it is proposed should govern source testing programs under the revised regulatory structure are supplied.

Appendix 9-1 - **SOURCE TESTING CODE**

Ontario's source testing code, which is under revision, is referenced. It is proposed that the revised version of this code will be the standard reference for use with the revised regulation.

Appendix 9-2 - **SOURCE TESTING METHODOLOGIES IN OTHER JURISDICTIONS**

A list of reference test methods from the U.S., which it is proposed should be used in Ontario, is supplied.

Appendix 10 - **AMBIENT AIR MONITORING**

The general requirements concerning ambient air monitoring are identified.

Appendix 10-1 - **AMBIENT AIR MONITORING APPROVED SAMPLING AND ANALYTICAL METHODS**

The sampling and analytical methods approved by the Ministry for pre-operational and post start-up ambient air monitoring are summarized.

Appendix 10-2 - **ASSESSING THE IMPACT OF AIRBORNE CONTAMINANTS ON SOIL AND TERRESTRIAL VEGETATION**

The Ministry's methodology for evaluating the effect of airborne contaminants on soils and vegetation are detailed as a standard measuring/assessment technique.

Appendix 11 - **QUALITY ASSURANCE FOR THE CLEAN AIR PROGRAM**

The general quality assurance requirements under the Clean Air Program concerning: continuous ambient air monitoring activities; continuous source emission monitoring activities; discrete ambient air monitoring activities; and discrete source emission monitoring activities are discussed.

APPENDIX 8

AIR QUALITY MODELLING

APPENDIX 8

AIR QUALITY AND MODELLING

DISPERSION MODELLING REQUIREMENTS

A. Ambient Air Modelling Requirements

After Proponents have met the emission control requirements for their contaminant releases, they must then demonstrate the attainment of satisfactory ambient air quality in the vicinity of their source complex. Evidence of the probable attainment of satisfactory air quality will generally be obtained through dispersion modelling.

The Ministry has developed a dispersion modelling package designed to assist in the assessment of ambient air quality due to existing and proposed emission sources. Dispersion modelling is the simulation of the dispersal of contaminants in the atmosphere using either computer models where the physical processes are represented by the solution of mathematical equations or physical, scale models (e.g., a wind tunnel or water tank models). Proponents will be required to perform a modelling assessment of ambient air quality. They may use the dispersion modelling package prepared by the Ministry or they have the option of using other mathematical dispersion models or physical models. However, if alternative modelling is selected it will be their responsibility to satisfy the Ministry that any predicted air concentrations lower than those indicated by the Ministry's modelling package have been properly evaluated both technically and theoretically.

B. Emission Sources to be Modelled

This regulation will apply to all proposed non-mobile sources and to all existing non-mobile sources requesting approval of proposed source changes. Also, existing emission sources will be subject to the emission control and ambient air quality/modelling requirements as this regulation is phased in.

Emission sources subject to control by this regulation include stacks, vents, chimneys, flares and cooling towers. Such sources are often referred to as point sources. The regulation also applies to volume or area sources including, but not restricted to tailings or coal piles, evaporation from ponds, leaks from valves, pipes, building doorways and windows, as well as all loading and unloading operations. An example of a stationary line source which would be subject to control is a conveyor belt.

For modelling ambient air quality, proponents will include all of the above emissions from their source complex. Background air concentrations due to other sources that affect ambient air quality in the vicinity of their source complex would be added to the modelled air concentrations due to their emission sources.

C. Emission Parameters

In addition to emission rates the proponent must derive the source parameters which define the manner in which the contaminants are released.

Proponents will use the maximum hourly averaged emission rates for each of their sources. For cases where the release duration is less than one hour an equivalent hourly average emission rate would be derived for modelling purposes. Proponent may provide a time series of emission rates which accurately reflect the variation in emission rates during the day, week or other averaging time period. If the modelling for a proposed source includes emission rate variations during the day, then those emissions would appear on the certificate of approval as emission limits for the source.

The source characteristics needed for modelling include the release height, the stack radius, efflux temperature and efflux velocity to calculate plume buoyancy and momentum, dimensions of nearby buildings or obstructions and dimensions of area or line sources. Detailed descriptions of the source information are provided in the Air Quality & Modelling Subappendix (Part) 1.

D. Ministry Modelling Methods

The Air Quality & Modelling Subappendix (Part) 2 describes the details of the Ministry's dispersion modelling package. These models were selected to handle the range of meteorological dispersion conditions and source characteristics in a scientifically credible manner. Since the models have to be routinely applied, analytical models were selected. The modelling package includes modelling techniques for building wakes, complex terrain and lakeshore situations, as well as elevated and near surface releases for the spectrum of dispersion conditions modelled.

The Ministry's modelling package can be run in two ways. In "worst-case" model runs proponents provide only source parameter information. The model internally searches through all feasible meteorological conditions to find the maximum hourly downwind concentrations due to an

individual source for the receptors of interest. A detailed multisource modelling assessment makes use of an input file of hourly meteorological data based on observations (a contiguous meteorological data set of at least one year is recommended).

Assessment of source complexes can then be divided into two types:

Type A: Worst-Case Modelling

Run the "worst case" model for each source of the contaminant. The "worst-case" results are then summed to give the maximum hourly concentration due to the source complex. Add the worst-case modelled concentration due to the proponent's source complex to the maximum background concentration. If this worst-case model result shows the potential to exceed the air quality standard for any appropriate averaging time then the proponent should undertake detailed modelling to assess model concentrations for multisource situations and for single source-cases with averaging times greater than 1 hour.

Type B: Significant Source Complexes and Background: Detailed Modelling

For detailed modelling, proponents require three input data sets. The data sets needed are the source parameters for all sources considered, a contiguous meteorological data set which covers all possible meteorological conditions and a set of receptor locations where the models are to calculate the contaminant concentrations.

Proponents will provide source parameters for their source complex. The Ministry will provide this data for other sources which give a worst-case hourly average concentration $\geq 5\%$ of the air quality standard within the radius of influence source complex. The radius of influence of a source complex is defined using the worst-case hourly concentration model as the distance to which emissions from these sources could result in an air concentration $\geq 5\%$ of the air quality standard. The maximum radius of influence is 25 km and the minimum radius of influence is 1 km.

The Ministry has prepared year-long hourly meteorological data sets for regional conditions in Ontario. For sites near large lakes or in complex terrain, these meteorological data sets can be used directly in the detailed modelling. Exceptions could be sites near large lakes or sites in complex terrain.

Type B sources may be divided into two groups:

(a) Proponents located in a region with a relatively uniform background concentration; i.e., no other source complex within the proponents' radius of influence produces a concentration $\geq 5\%$ of the air quality standard' (AQS) would perform detailed modelling for their own source complex and would add to this the background concentrations for comparison with the air quality standards or their surrogates for the appropriate averaging times.

(b) If other sources within 25 km of the proponents' source complex could produce a concentration $\geq 5\%$ of the air quality standard within the proponents' radius of influence then they must be included in multiple source modelling. Background concentrations due to uniformly distributed sources (i.e. area sources such as cars or space heating) or long range transport of the contaminants concerned would be added to the concentrations produced by the multisource modelling.

Details of the Ministry's modelling methods are described in the Air Quality & Modelling Subappendices. Part 1 describes the source parameters needed and provides directions for performing the modelling. Part 2 provides a detailed description of the equations in the models. Part 3 discusses the meteorological input data for detailed modelling and how such data sets are produced. Part 4 provides diskettes of a model code with users guides for installing and running the model codes.

E. Background Air Concentrations

Since proponents must show that ambient air quality standards for the appropriate averaging times will probably be met, background contaminant concentrations must be determined and added to the impact of emissions from source complexes. Background concentrations include contributions from significant point sources in the vicinity of the proponent's source complex as well as small point sources, area sources such as cars or space heating and long range transport of the contaminant.

Background concentrations can be determined from either emission data or from monitoring data.

(a) Emission data

The Ministry would provide proponents with source characteristics data for additional significant point sources which might affect ambient air quality in the vicinity

of a source complex. For regions where data are available, the Ministry will also provide either gridded area emissions (i.e. due to cars, space heating, small point sources, etc.) or maximum ground level concentrations derived from the emission data. These modelled background concentrations are derived using either the Ministry's multisource modelling package or other urban models (i.e. plume or Eulerian models).

(b) Monitoring data

Where the data are available the Ministry will provide air quality monitoring data for representative urban and non-urban areas in Ontario. As discussed in Appendix 10, proponents could be required to provide site-specific background monitoring data if significant local area or point sources contribute to background concentrations and emission data are not known accurately enough to model background concentrations. This might occur near highways, in urban street canyons or in areas with many small point sources. The maximum monitored background concentration is defined in Appendix 10.

The method for determining background concentrations depends on the type of modelling performed and on the data available.

Type A Modelling: When "worst-case" modelling is performed, maximum background air concentrations must be added to the proponent's source complex contribution.

(a) If there are no significant point sources, other than source complex for which application is being made, then maximum background concentrations would be derived from either modelled area source emissions or the maximum monitored concentrations. The maximum background values would be for the averaging times of the appropriate air quality standards.

(b) For cases where there are other significant point sources within a radius of influence; either (i) the Ministry will provide modelled maximum background concentrations due to both significant point and area sources for regions where such data are available; or, (ii) the proponent would do worst case model runs for significant point sources and add these maximum values plus either modelled area sources or monitored uniform background concentrations to the maximum concentration due to the proponent's source complex.

Type B Modelling: When detailed multisource modelling is performed, all significant point sources are included in the dispersion model runs. A contiguous hourly meteorological data set is

used in this analysis.

(a) If a contiguous time series of background concentrations (modelled area source concentrations or monitoring data) is available these data could be added to the time-series of model results for the proponent's source complex and other significant point sources. The data set would be analysed to compare the modelled ambient air concentrations with the air quality standard for the appropriate averaging time.

(b) If a time sequence of modelled area source concentrations is not available and monitoring data are not continuous (i.e., at least 70% of a year's data is needed) the proponent must use derived maximum values for background concentrations.

Subappendix (Part) 1 of this Appendix provides more information on the derivation of background concentrations from either emission or monitoring data. Appendix 10 outlines the monitoring options for determination of background concentrations and the requirements for compliance testing after the source complex is in operation.

F. Compliance with Air Quality Standards

Once proponents have performed dispersion modelling calculations to derive concentrations due to their own source complex plus background sources, the results must be compared to the air quality standards shown in Appendix 6 or to another determinant of acceptable air quality, as detailed in the footnote on page 4 of this Appendix. Depending on the contaminant these air quality standards can range from one hour to one year.

To be in compliance with the Regulation for Level 1 contaminants, proponents must show that air concentrations in the vicinity of their source complexes are less than or equal to each applicable air quality standard.

For Level 2 and 3 contaminants, proponents must show that modelled air concentrations in the vicinity of their source complexes are less than or equal to any standard greater than one hour. For comparison with a one-hour standard, proponents have the option of showing that the 8th highest modelled hourly average concentration in a year-long data set is less than the hourly air quality standard.

If proponents are emitting a Level 2 or 3 compound and has more than seven hours of modelled exceedances of a one-hour standard, supplementary controls might be used to qualify for

compliance with the hourly air quality standard.

G. Supplementary Controls

Supplementary controls mean reducing emissions during meteorological conditions which could produce high concentrations of the contaminant. The Ministry would consider supplementary emission controls as a method of complying with an air quality standard in the following circumstances.

New Sources

The contaminant concerned is classified as Level 3 and the proponent has installed bottom-of-the-stack controls corresponding to Level 2 or Level 1 technology.

Existing Sources

- (a) For existing sources with no existing supplementary control program, proposals will be considered for Level 3 contaminants if the proponent combines this with Level 2 or Level 1 control technology and for Level 2 contaminants if proponents combine this with Level 1 control technology.
- (b) For existing sources currently under control orders detailing supplementary control plans (all are for SO₂ sources), the Ministry will allow the use of such plans but will require improvements in control technology to Level 1 and documented compliance with the SO₂ air quality standards after a phase-in period.

In all cases the proponent must submit a plan detailing the conditions under which emissions would be cut and show that this plan would result in compliance with air quality standards. In Subappendix 5 entitled "Supplementary Control Programs", the necessary elements of a supplementary control plan are described. The major elements of this plan are ambient air monitoring, continuous measurement and prediction of meteorological conditions with dispersion modelling of the potential adverse effects of these conditions and a description of what emission cuts would occur along with information on how quickly these cuts could be implemented.

H. Stack Height Limits for Modelling

To reduce reliance on dispersion to achieve acceptable air quality, a limit will be imposed on the stack height used for proponent's stacks when estimating downwind concentrations.

For point emissions from a new stack or vent within source complexes, the maximum stack height used in dispersion calculations will be the greater of 100 meters or 2.5 times the height of the highest nearby building (see Air Quality & Modelling Subappendices Parts 1 and 2).

For stacks outside proponents' source complexes, the actual stack height should be used in dispersion calculations.

THE CLEAN AIR PROGRAM

AIR QUALITY MODELLING

APPENDIX 8-1

A General User's Guide for

Source Assessment

Table of Contents

CHAPTER 1: PRACTICAL ASPECTS OF SMALL SCALE MODELLING APPLIED TO THE REGULATION OF AIR QUALITY	1
1.1 Emission Sources Subject to Regulatory Control:	1
1.2 Definition of the Sources for Dispersion Modelling:	2
1.3 Air Quality Modelling for Emissions Control:	3
1.4 Practical Considerations for Dispersion Modelling:	4
 CHAPTER 2: SOURCE CONSIDERATIONS	 8
2.1 Identification of the Sources:	8
2.2 Source Emission Parameters:	9
2.2.1 Contaminant emission rates: (Q, grams/second)	9
2.2.2 Source release height: (z_s , metres)	10
2.2.3 Source efflux buoyancy flux (F , m^4/s^3) and vertical momentum flux (F_m , m^4/s^2) parameters:	10
2.2.4 Source Dimensions (metres):	11
2.3 Source Location Parameters:	12
2.3.1 Absolute site location:	12
2.3.2 Relative source location:	13
2.3.3 Site buildings and structures:	13
2.3.4 Representative Surface Roughness Length Scale:	14
2.4 Physical Setting of the Site:	15
2.4.1 Lakeshore settings	15
2.4.2 Complex Terrain:	16
 CHAPTER 3 THE ROLE OF AIR QUALITY STANDARDS AND BACKGROUND AIR CONCENTRATIONS IN SOURCE COMPLEX ASSESSMENT	 17
3.1 Ambient Air Standards	17

3.2 Background Concentrations	18
3.2.1 Emission Data	18
3.2.2 Monitoring Data	18
3.2.3 Determining Background for Type A and B Modelling	19
 CHAPTER 4 SIMPLIFIED MODELLING FOR ASSESSMENT OF SOURCE COMPLEXES	20
4.1 Applicability for the "Worst-Case" Modelling	20
4.2 "Worst-Case" Modelling Methodology	21
4.3 "Worst-Case" Input Source Parameters	26
4.4 Application of "Worst-Case" Modelling Results	27
 CHAPTER 5 DETAILED DISPERSION MODELLING FOR SOURCE COMPLEX ASSESSMENT	30
5.1 Detailed Modelling Methodology	31
5.2 Detailed, Dispersion Modelling Package Input	40
5.2.1 Source Parameters	40
5.2.2 Meteorological Data for the Site	42
5.2.3 Receptor Locations	44
5.3 Application of Detailed Modelling Results	46
 APPENDIX A "TECHNIQUES FOR DEFINING BUILDINGS AND STRUC- TURES WITHIN OR NEAR THE SOURCE COMPLEX FOR AIR QUALITY MODELLING PURPOSES"	47
 APPENDIX B "WORST-CASE" MODELLING METHODOLOGY	48

CHAPTER 1: PRACTICAL ASPECTS OF SMALL SCALE MODELLING APPLIED TO THE REGULATION OF AIR QUALITY

To maintain satisfactory air quality it is necessary to regulate current and future contaminant emissions such that when the ambient air quality is determined it does not exceed the established air quality standards. Evidence of the probable attainment of satisfactory air quality will generally be obtained through dispersion modelling.

The Ministry has developed a dispersion modelling package designed to assist in the assessment of ambient air quality due to existing and proposed emission sources. Dispersion modelling is the simulation of the dispersal of contaminants in the atmosphere using either computer models where the physical processes are represented by the solution of mathematical equations or physical, scale models (e.g., a wind tunnel or water tank models). This Document describes the use of the Ministry's modelling package which includes several mathematical computer models.

1.1 Emission Sources Subject to Regulatory Control:

The proposed new regulation will apply to all new (proposed) sources of contaminant emissions into the atmosphere and to all existing sources requesting approval of proposed source changes. Also existing emissions will be subject to review as the application of this regulation is phased in for existing sources.

A source of atmospheric emissions may be any stack, vent, process, system or area that produces or releases an emission into the atmosphere. Stacks, vents, and chimneys composed of perhaps several stacks or flues are examples of stationary sources. Examples of releases due to a process include flares and cooling towers. Often an emission released over a small area such as a stack or vent opening is referred to as a point source. Area and line sources refer to emissions occurring over an area with significant physical dimensions. Examples of area and line sources, respectively, are tailing or coal piles and uncovered conveyor belts. These may also be examples of fugitive sources. A fugitive source is any source where the emissions are not collected or contained such as leaks from doorways or windows and emissions from loading and unloading material. The new regulation will include fugitive emissions.

Specifically not included in the new Regulation are mobile sources and certain temporary sources. However, these sources are subject to other Regulations. If a user has any questions regarding the applicability of this new Regulation to their sources they should contact the Ministry for clarification.

To proceed with an assessment of the contribution of a user's source(s) to the local air quality it is necessary for the user to define his existing, permitted and proposed contaminant emissions. Chapter 2 details the source information required for the Ministry's modelling package. Emissions of all durations must be considered.

1.2 Definition of the Sources for Dispersion Modelling:

In order to use the modelling package one must first define the required emissions parameters which describe the contaminant sources for the dispersion models. The emissions parameters required for all of the user's existing and proposed sources include:

- the hourly emission rates for all contaminants where releases for durations of less than one hour are expressed as a rate equivalent to the hourly emission amount and where the emission rates include the maximum hourly rate which is currently permitted or which is being requested for a proposed source;
- the emission release height relative to average ground level in the area of the user's sources;
- parameters for determining the buoyancy and upward momentum of the emissions efflux such as stack radius or area, efflux temperature (or density), and the efflux flow rate;
- the source size and shape for area and line sources.

In addition, the user must locate their sources within their site. A site may be a plant complex including numerous sources and several buildings spread over a large area or it may be a single stack or vent on a small building or property. Location of the user's sources requires defining the relative placement (usually in meters) of each source with respect to some clearly defined reference location usually within the source complex.

To complete the description of the sources it is necessary to define the location of the releases relative to buildings and other structures on and near the site and to define the dimensions of these structures. This information provides the data required to incorporate within the models a consideration of the effects of structure wakes on the contaminant dispersion.

The absolute location and physical setting of the source complex under consideration also may be important for subsequent air quality modelling. Hence the user should be prepared to provide information of this nature.

The source parameters will be discussed in detail in Chapter 2.

1.3 Air Quality Modelling for Emissions Control:

To ensure that satisfactory air quality is maintained the Ministry proposes to define ambient air standards which would establish the maximum acceptable ambient concentrations of contaminants. These standards will reflect averaging times appropriate to the contaminants' effects (times from 1 hour to 1 year). To determine that satisfactory air quality is probably attained the Ministry proposes the use of air quality modelling to assess that proposed and existing emissions do not result in ambient concentrations which exceeds the standards.

The modelling package prepared by the Ministry has been developed based on the following criteria:

- the models selected had to be applicable to calculation of air quality over the various time scales for which standards have been defined (i.e., 1 hour to 1 year);
- the models had to be scientifically credible (i.e., have been subject to scientific peer review) and reflect our current knowledge of pollutant dispersion in the atmosphere;
- the evaluations of model calculations with monitoring data had to show good performance in the prediction of down-wind concentrations;
- the models had to be feasible for routine application.

The models reflect variations in the dispersion of pollutants according to the atmospheric conditions in the planetary boundary layer and the pollutant release height. The planetary boundary layer is that region of the atmosphere which is nearest to the ground and where the atmospheric conditions are directly influenced by the presence of the surface. Also considered within the modelling package are the special source situations: sites located near a lake shore; sites located near or within complex terrain; sites where buildings influence pollutant dispersion (building and structure wakes).

A proponent may use the dispersion modelling package prepared by the Ministry or they have the option of using other modelling including other mathematical dispersion models or physical models. However, if the proponent selects alternative modelling it will be their responsibility to satisfy the Ministry that any resulting emission limits which are not as low as those indicated by the Ministry's modelling package have been properly evaluated both technically and theoretically.

The Ministry's modelling package has been developed for use without requiring a detailed knowledge of the air quality models included in the package; however, for interested users

details of the models are given in Part 2 of this Document entitled "Detailed Description of the Full, Multi-Source Air Quality Modelling Techniques for Calculation of Local Air Concentrations".

1.4 Practical Considerations for Dispersion Modelling:

To calculate the ambient air, ideally one would estimate the contribution from each source (point, area or line) in the region to the air quality under all possible meteorological conditions. As well, it may be necessary to include the contributions from long-range transport and/or natural emissions to the overall air quality.

Frequently it is not necessary or practical to undertake a full set of model simulations for all sources in the region to estimate the air quality. For simplification purposes it is possible to divide the sources complexes being reviewed into two types:

Type A: Source complexes which yield small contributions to ambient air concentrations of a contaminant even under worst-case conditions and which are located in regions with relatively good air quality. Where source complexes consist of more than one source, the worst-case for the total plant can be computed by summing the worst-case for individual points of emissions. A step by step description of how to perform worst case modelling is presented in Chapter 4. If the worst case concentration for all point sources plus the background concentration does not exceed the air quality standard then no further modelling is required. Chapter 3 discusses background air concentrations in the vicinity of a source complex.

Type B: Source complexes, which when assessed with the worst case modelling techniques used for Type A sources, have shown the potential to have the contribution of the source complex plus background concentrations exceed the air quality standard for the appropriate averaging time, must undertake a full set of model simulations to estimate air quality. Chapter 5 discusses detailed modelling for a source complex.

Type B sources may be divided into two groups:

- (1) Source complexes located in a region where a relatively uniform background concentration for the particular contaminant exists, regardless of origin.
- (2) Source complexes located in a region with several other large source complexes emitting the same contaminant in significant amounts.

The assessment of the contribution of emissions from a source complex to the ambient air quality may proceed in the following manner:

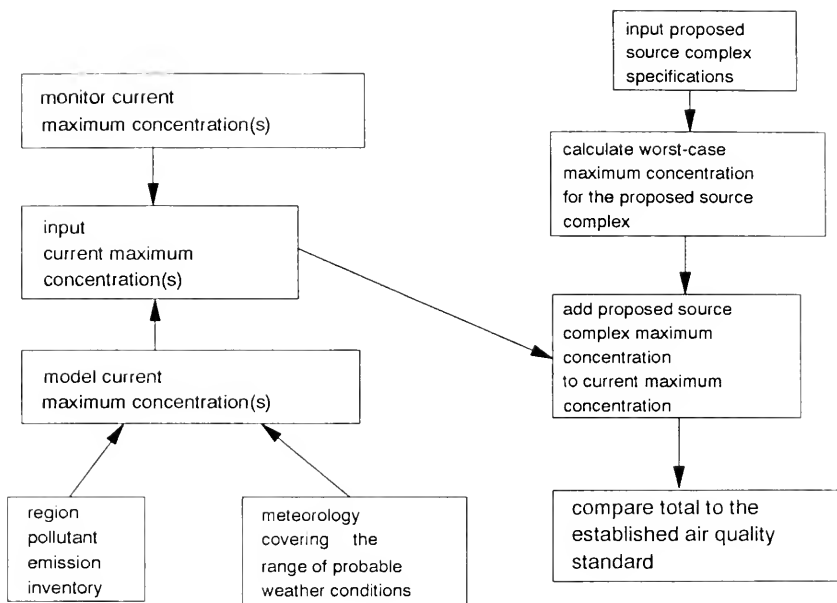
Type A: Minor Source Complexes: Worst Case Modelling

A simplified modelling package has been prepared by the Ministry to calculate the maximum hourly averaged concentration due to source emissions under worst-case meteorological conditions (also see Chapter 4 and Appendix B). Worst-case meteorological conditions are defined as the conditions which contribute to the highest ground-level concentration from a source. The worst-case modelling requires only that the user define the sources parameters (e.g., the stack height and diameter, the expected effluent vertical flow rate and average temperature, and the surface roughness length scale). This package of models predicts the maximum possible (worst-case) value of the air concentration, per unit of emission and the downwind location from the source at which this concentration will occur. All sources of the contaminant are processed through the worst case model then their individual hourly averaged maximum contaminant concentrations are weighted by their emission rate and summed. This summation can be performed separately for the three stabilities calculated in the model with the overall maximum selected.

For sources emitting contaminants with hourly averaged standards the worst-case modelling results may be compared to the standard for the contaminant. If this modelling indicates that the total contribution of these sources plus the background contribution due to area sources and long range transport is less than the air quality standard then no further modelling is required.

Contaminants with standards established for periods longer than one hour may also be assessed using the worst-case modelling if the user is willing to make the conservative comparison of the worst case hourly average concentration directly with a standard established for a longer averaging period. For relatively small sources assessing contaminant emissions with 24 hour standards using this approach may not be excessively conservative. For contaminants with standards given in terms of 30 day or 1 year averages the user may also choose this extremely conservative option of directly comparing the modelled worst-case hourly average with these standards. If the proponent can demonstrate through an analysis of meteorological data that the worst case receptor was only affected for part of the 30 day or annual average period by the sources in the airshed, this could be taken into account. Otherwise the user should undertake detailed modelling for their sources to develop modelled concentrations for averaging periods comparable to those used to define the standards.

Schematically, the sources belonging to Type A can be assessed in the following manner:



Type B: Significant Source Complexes and Background: Full Modelling

Full modelling using an hourly meteorological data set must be undertaken if the worst case modelling described for Type A sources indicates the potential to exceed the air quality standard for some averaging time.

To proceed with the detailed modelling of sources belonging to Type B the user requires three sets of data. These data sets are the source parameters for the group of sources being considered, a meteorological data set which describes the possible atmospheric conditions which could occur at the site under review, and a list of locations relative to the site location where the models are to calculate the contaminant concentrations. The user is responsible for providing the source parameters for their source complex. The Ministry will provide the data for other sources which are large enough to have a significant contribution to contaminant concentrations in the region of the source complex. The Ministry will prepare meteorological data sets giving regionally representative atmospheric conditions which in most cases may be used directly in the detailed modelling. The exceptions occur when the site under review is located near a large lake or in

complex terrain. These exceptions are discussed further in Chapter 5. The method for determining the list of locations where concentrations are to be calculated, the receptor list, is also detailed in Chapter 5.

(1) Uniform Contaminant Background Situations

If background concentrations of the contaminants concerned are uniformly distributed (i.e. due to area sources or long range transport), the proponent would perform multisource modelling for the emissions from their own source complex and would add to this the current maximum background concentration. The sum is then compared to the air quality standards for the appropriate averaging time.

This approach for estimating the maximum concentration is applicable only if the background concentration of the pollutant is the result of an essentially homogeneous distribution of sources of the pollutant or long-range transport. If the spatial distribution of the background is non-homogeneous it will be necessary for the proponent to consider the distribution of the background concentration as part of a detailed modelling assessment.

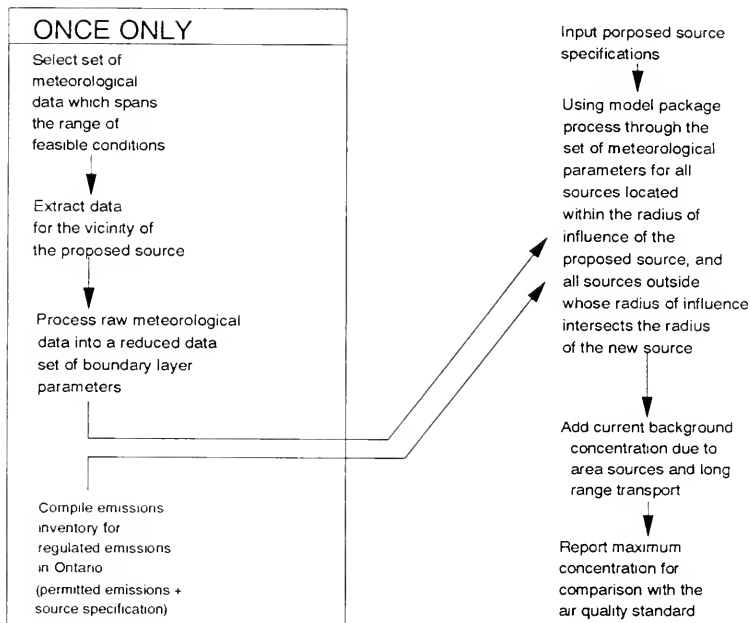
(2) Multiple Source Complex Situations - non-uniform contaminant background situation

In a region where several source complexes of the same pollutant contribute to the concentration of the pollutant, the concentration pattern may be highly dependent upon the distribution of the sources and the meteorological conditions. The results of the addition of another significant source to such a region can only be assessed by full modelling of the contributions of all sources in the area to the concentration pattern. Permitting a new significant source into a region with several sources can be expected to increase the maximum pollutant concentration. Also, the location at which the maximum occurs may be expected to change.

Multiple source modelling would be performed for all point sources within 25 km which give a worst case hourly average concentration $\geq 5\%$ of the air quality standard within the radius of influence of the proponent's source complex. The radius of influence of the proponent's source complex is defined using the worst case hourly concentration model as the distance to which these sources can exceed 5% of the air quality standard. The maximum radius of influence is 25 km and the minimum radius of influence is 1 km.

Maximum background concentrations due to uniformly distributed sources or long range transport of the contaminants concerned would then be added to the maximum contribution from multisource modelling. This result would then be compared with air quality standards for the appropriate averaging time.

A schematic chart of the manner in which sources belonging to Type B could be assessed is shown in the following diagram:



CHAPTER 2: SOURCE CONSIDERATIONS

This Chapter provides a detailed description of the source information which the proponent or user of this modelling package must provide in order to proceed with a modelling assessment of their source complex emissions.

2.1 Identification of the Sources:

A source of atmospheric emissions may be any stack, vent, process, system or area that produces or releases an emission into the atmosphere. It is the responsibility of the proponent to identify all emission sources at their site. This may include:

- existing sources with Certificates of Approval;
- existing sources such as fugitive sources which at present operated without a Certificate of Approval;
- proposed sources.

For the purposes of air quality modelling each of the sources must be described by a set of source emission parameters and source location parameters.

Source parameters should be determined by measurements where possible or by calculations using acceptable engineering principles appropriate to the source design and control technology. All source parameters and the manner in which they have been determined are subject to review by the Ministry.

2.2 Source Emission Parameters:

To describe the sources of contaminant emissions for the purposes of dispersion modelling it is necessary to define several parameters:

- contaminant emission rates;
- source release height;
- source efflux buoyancy and vertical momentum flux parameters;
- source dimensions.

Prior to defining the source emission parameters the proponent should ensure that, at least, the minimum required emission control technology appropriate to the contaminants has been applied to the sources and, hence, are reflected in the emission parameters. This is discussed in the Emission Standards section (Appendix 7) of the Clean Air Program.

2.2.1 Contaminant emission rates: (Q , grams/second)

For each contaminant released from a source it is necessary to determine the hourly averaged emission rate based on the hourly contaminant emission amount (in grams) divided by the time period (3600 seconds). Emissions need not occur continuously over the hour period but the hourly average should correctly reflect the total hourly amount. If a source were releasing a number of contaminants, emission rates would be derived for each.

In many cases, source hourly averaged emission rates may vary significantly; hence, it is necessary that the maximum hourly average emission rate be defined for each contaminant. Hourly average refers to the average over any period of an hour but not necessarily clock hours.

In addition, if the proponent or user wishes they may provide a series of emission rates which accurately represent the variation of emission rates during the day, week or plant process. If the modelling for a proposed source includes the emission rate variations during the day, then those emissions would appear in the Certificate of Approval as emission limits for the source.

In the case of sources with existing Certificates of Approval for which re-approval is not being requested the user should report the contaminant emission rates and source parameters which accurately reflect the configuration used to obtain the Certificate(s) of Approval although the sources may be operating at less than the approved emission rates.

2.2.2 Source release height: (z_s , metres)

The physical release height of a contaminant is measured from the average grade (ground) level in the site where the source is located to the top the stack, vent or chimney emitting the contaminant. For fugitive emissions the release height would be defined by the height from grade of the release opening. The release height of sources located on buildings or structures should be measured from average grade level irrespective of the building height.

In some cases defining the release height of fugitive or area sources may not be as obvious as it is for point sources. For examples, emissions from tailing piles or material loading and unloading may not have clearly defined point of release; however, the contaminant can be described as being released into a volume of space at an average height and the volume can be described in terms of crosswind volume width and volume depth. The user is referred to Subsection 2.2.4 for a description of the information required to define the dimensions of a source.

2.2.3 Source efflux buoyancy flux (F , m^4/s^3) and vertical momentum flux (F_m , m^4/s^2) parameters:

To define the source buoyancy and upward momentum flux it is necessary to determine the volume flux of the source and density difference between the efflux and ambient air. The source buoyancy and momentum flux parameters should be chosen to correspond to the contaminant emission rates and may differ for contaminants released from the same source as the release conditions may change for different contaminants.

In the case of emissions from a relatively circular, vertical stack or vent opening the parameters required by the dispersion modelling package to calculate the source buoyancy and vertical momentum fluxes are:

- The efflux (exit gas) temperature at the release height (T_s , °Celsius).
- Efflux velocity at the release height (w_s , metres/second).
- Source radius at the release height (r_s , metres).

If the stack or vent opening is not circular then the area of the opening can be used to derive a radius of a circle of equivalent area.

Other Considerations:

There are several special cases for unusual sources which can be considered when deriving buoyancy and vertical momentum fluxes. These special cases are: flare stacks, cooling towers, density differences due to the molecular weight of the emissions and non-vertically oriented stacks.

The buoyancy of emissions from flares is enhanced by the heat released during the burn. Directions for calculating the buoyancy of flare emissions are included in Part 2 of the Document. To proceed with dispersion modelling of flare emissions the user must calculate the heat released during the flaring operation.

Cooling tower emissions include large amounts of water released. The special thermodynamic aspects of cooling towers are discussed in Part 2 of this Document. In general the input parameters used for a standard point source will give reasonable results for cooling towers.

The molecular weight of the emitted gas can effect the buoyancy if the emission temperature is near the ambient temperature. Since the modelling package does not deal with heavy gases, the net buoyancy due to both temperature and molecular weight effects must be greater than or equal to zero.

When the stack efflux is not oriented vertically, the vertical component of the efflux velocity should be used to derive the vertical momentum flux. The buoyancy flux on the other hand will use the total efflux velocity.

2.2.4 Source Dimensions (metres):

Sources with significant physical dimensions such as area sources may be defined within the dispersion modelling in terms of the cross wind and long wind dimensions. As the wind direction may vary through 360 degrees, it is necessary to provide a series of coordinates (locations) to outline the source and provide the data needed to calculate source width in any direction. The coordinates defining the source should be consistent with the manner in which the source location parameters are defined (i.e. subsection 2.3). If the dimensions of the source are not approximately equal in all directions as would be the case for an extended line source then the source should be divided into a group of smaller area sources with essentially equivalent dimensions.

In some cases a source may be emitting into a volume of air (i.e. a tailings or coal pile). In these cases a source height is also required to describe the extent of the vertical domain into which the source emits.

2.3 Source Location Parameters:

The source location parameters required for application of the Ministry's dispersion modelling are:

- the absolute location of the site where the sources are located;
- the relative location of each source with respect to some reference point within the site;
- the dimensions and relative location of buildings or structures located near the sources;
- the surface roughness length scale, z_0 , representative of the area of the source complex.

2.3.1 Absolute site location:

To identify the source(s) under consideration it is necessary for their site location to be absolutely defined. The site may be a plant complex spread over a large area including numerous sources and structures or may be a small building or property with a single stack or vent. Whatever the size of the site, the user should select a fixed reference point within

their site which will be used to define the site location or coordinates. Possible choices for a site reference point include the location of a major source or building within the site property.

Once the site reference point has been selected its location should be defined using the Universal Transverse Mercator (UTM) grid. To determine the UTM coordinates of the site reference point the user should refer to the maps of the National Topographic System published by Energy, Mines and Resources Canada at a scale of 1:50,000. Superimposed on these topographic maps are the Universal Transverse Mercator grid lines at intervals of one thousand metres which permit the user to identify the coordinates of their site to within approximately 100 metres using the directions provided on the maps. To complete the UTM coordinates of their site the user should also report the UTM grid zone designation printed on the map. Maps at a scale of 1:50,000 are available for all regions of Ontario and may be obtained from the Canada Map Office, Department of Energy, Mines and Resources, Ottawa. Individual maps cover an area of approximately 40 km east-west and 25 km north-south. In many areas of the province maps on a scale of 1:25,000 are available to better assist the user in defining the site absolute UTM coordinates.

In addition to the site's UTM coordinates the proponent should provide an accurate street or lot address for the site under review.

2.3.2 Relative source location:

The location of the sources to be considered using the dispersion modelling package requires that their relative placement be defined with respect to the clearly defined reference point within the site. Source location within the modelling package is defined using a rectilinear grid system oriented with respect to true north. Each source is located by two measurements: the distance east of the fixed, site reference point measured in metres (distances west of the reference point are reported as negative values); and the distance north of the reference point (distances south of the reference point are reported a negative values). These two measurements define the relative coordinates of the source referred to in the model as the source x-y coordinates.

Source coordinates may be measured from an accurate site plan or plant engineering drawings for the site.

In the case of area and line sources the source coordinates should define the approximate centre of the source.

2.3.3 Site buildings and structures:

In the majority of cases within and near the proponent's site there will be a number of existing or proposed buildings or structures which are close enough to the source to effect local air

flow and, hence, the manner in which the pollutants are dispersed. Buildings and structures are defined for modelling purposes as being close to a source if the horizontal distance between the source and the building or structure (measured from the closest face of the building) is equal or less than the greater of 2 times the height or one times the cross-wind width of the building or structure. Hence, the user should consider all buildings or structures in terms of their relative separation from the sources and for each source flag the buildings and structures which met the model criterion as close. Each flagged building or structure must then be defined in terms of their location, height and horizontal dimensions for the model.

The horizontal dimensions of the buildings and structures are used in the model to define the cross wind width of the structure. Because the wind may be from any direction, sufficient information regarding the horizontal extent of the building must be available. Simple rectangular structures may be defined by location of one corner, the lengths of the sides of the building plus the building's orientation with respect to true north. For more complex structures it is easier to define a series of x-y coordinates relative to the fixed reference point for the site to outline the sides of the structure. To standardize input for the dispersion model each structure is assign a number followed by the structure height (in metres), the number points in the series of coordinates used to define a piece wise linear outline of the structure, and the series of paired x-y coordinates for the structure in metres east and north of the site reference point listed in order around the structure (i.e., the first set of coordinates are to be jointed with the last pair of coordinates to complete the structure outline).

Many sites consist of several complex structures and buildings which are located immediately adjacent to each other. Also many structures have complicated vertical profiles or roof lines. Appendix A provides generalized guidelines for determining structure and building dimensions in a manner consistent with the modelling techniques used in the Ministry's dispersion modelling package.

2.3.4 Representative Surface Roughness Length Scale:

The surface roughness length scale has been related to the size of the surface roughness elements such that, z_0 , may be approximated by 1/30th of the height of the surface cover (e.g., grasses, trees, building) located in area of the source complex. An accurate determination of the roughness length of a site would include consideration of the nature the underlying surface which the air would pass over (the fetch) prior to reaching the point of interest. For practical application in the dispersion modelling assessment using the Ministry modelling package it is recommended that a representative roughness length scale be defined for the source complex. This value of z_0 should be based on the average nature of the surface

in an area extending for 1.5 km in all directions from the site. If the average nature of the surface may be defined by a typical type of ground cover then an appropriate value of z_o may be selected using the following table.

ROUGHNESS LENGTHS FOR VARIOUS SURFACES *	
Surface	z_o (cm)
Very smooth (ice, mud flats)	0.001
Snow	0.005
Smooth sea	0.02
Lawn, grass up to 1 cm high	0.03
Lawn, grass up to 5 cm high	1-2
Lawn, grass up to 50 cm high	4-9
Fully grown root crops	14
Forest	50-100
Urban core	100

* After Pasquill (1974) and Seinfeld (1975)

2.4 Physical Setting of the Site:

The physical setting of the proponent's site may play a significant role in the dispersion of contaminants. In addition to building and structure wakes, two special source settings have been identified: lakeshore situations, and complex terrain. Also whether the site is in an urban/industrial setting verses a rural setting should be noted.

The physical setting of a site can effect the results of the modelling assessment of air quality due to emissions from its sources in two ways. First the presence of a major body of water, complex terrain or large urban/industrial area can change the local meteorological conditions which influences the dispersion of pollutants. Second, in the case of complex terrain or built-up areas there may be locations which are significantly elevated above grade level at the source site and, hence, are of critical concern as they may be directly downwind for elevated releases at the site under consideration.

Locations of critical concern are referred to as critical receptors for model assessment purposes and should be identified for the user's site by their x-y coordinates relative to the fixed reference point defined for the site as per Subsection 2.3.3 and their height above grade as defined at the

user's site. In the case of a hill or structure the height would refer to the maximum height. In addition the user should note the nature of the critical receptors (Eg. an apartment building, a hill or ridge).

2.4.1 Lakeshore settings

A site is considered to be in a lakeshore setting if it is located within 15 kilometers of a major body of water. For modelling purposes in the Province of Ontario the major water bodies are: James Bay, Hudson Bay, Lake Superior, Lake Huron including Georgian Bay and the North Channel, Lake St. Clair, Lake Erie, Lake Ontario, Lake Simcoe, Lake Nipissing, Lake Nipigon and the Lake of the Woods. These bodies of water were selected based on the criteria of requiring a minimum 20 kilometers width of open water (fetch over water) to establish a stable marine overwater boundary layer which subsequently affects pollutant dispersion over land.

If the assessment of the proponents sources indicates that worst case modelling cannot be used to model the impact of their sources then it may be necessary for the user to revise the regional representative meteorological dataset used for the full model assessment so that local meteorological conditions are represented in the modelling assessment. Users affected by this requirement are referred to Chapter 5 for a discussion of the full modelling package and to Part 3 of this Document for detailed procedures for localization of the meteorological dataset.

2.4.2 Complex Terrain:

The terrain features surrounding a source complex may influence the meteorological conditions in the area of the sources if they are located closer than the greater of 2 times the height or 2 times the length of the terrain feature from the top of the feature. For very long features such as the Niagara Escarpment the effect may extend to 15 kilometres.

Complex terrain can alter contaminant dispersion. The proponents site would be considered to be complex terrain if:

1) The release height is less than two times the maximum terrain height. The maximum terrain height (Δh) is defined as the difference between the highest level (including tree tops) and the lowest level within the larger of 20 times the stack height or 1 km from the source complex.

2) In addition, the gradient of the terrain height with distance, Δx , from the source complex (i.e. $\Delta h/\Delta x$) must be greater than 1/5.

These requirements are discussed in Part 2 of the Document.

Sources located in a very complex setting may require special consideration including local monitoring of the meteorological conditions.

CHAPTER 3 THE ROLE OF AIR QUALITY STANDARDS AND BACKGROUND AIR CONCENTRATIONS IN SOURCE COMPLEX ASSESSMENT

As part of the requirements for obtaining Regulatory approval for proposed sources within a source complex it is necessary to show that there will be probable attainment of satisfactory local air quality if the plant emissions are permitted. Satisfactory air quality for specific contaminants is defined by the air quality standards set by the Ministry. Local air concentrations of a contaminant will be the result of the proponent's existing and proposed emissions plus a background concentration due to other sources of the contaminant within the region and, perhaps, due to long range transport of the contaminant into the area. Hence, a dispersion modelling assessment of the probable attainment of an air quality standard requires that maximum background contaminant concentrations be determined.

3.1 Ambient Air Standards

Ambient air quality standards have been set by the Ministry for a large number of contaminants and a list of these standards is given in Appendix 6 which accompanies the proposed Regulation. This schedule lists the contaminant name, the units used to measure concentration and the ambient air standards with their associated averaging times.

Some contaminants have more than one standard each applicable to a different averaging period or averaging method. In general, when establishing these standards the Ministry considered the averaging times appropriated to the effect of each contaminant. The exception is substances where the effect is malodorous. The criteria for standard setting for odourous material is often olfactory response to short-term (10 minutes or less) peak concentrations. In these cases standards expressed as hourly averaged concentrations which take into account the shorter term data will be prepared for comparison with model results.

When there is more than one standard for a contaminant which may be emitted by the source complex, the proponent must demonstrate that there will be probable attainment of all the applicable standards in the region of the source complex when both concentrations due to the plant emissions and background concentrations of the contaminant for the appropriate averaging periods are considered.

If the source complex emissions include contaminants not listed in the Schedule the proponent should contact the Ministry for guidance.

3.2 Background Concentrations

Background concentrations within the radius of influence of the proponents source complex include possible contributions from significant point sources, small point sources, area sources such as cars, space heating, natural emissions or fugitive dust and long range transport of the contaminant. The two data bases which could be used to derive background concentrations are emission inventory data and monitoring data.

3.2.1 Emission Data

The Ministry will develop and maintain an emission inventory of point sources for the contaminants listed in Appendix 6. For significant point sources outside the proponent's source complex, the Ministry will provide emission rates and source characteristics data when this information is available.

Where data is available, the Ministry will develop gridded inventories for area emissions due to small point sources, vehicles, space heating, natural emissions, fugitive dust, etc. The Ministry will provide the data to the proponent if requested. Background concentrations can then be derived for the appropriate averaging times by modelling these emissions. The modelling can be performed by using either the Ministry's multisource modelling package or an alternative plume or Eulerian model. The Ministry would review any modelled background concentrations produced by the proponent.

The Ministry will model background concentrations for both area sources and significant point sources for some industrial and urban areas and some representative non-urban areas in Ontario. Where these data are available, maximum background concentrations appropriate for the vicinity of the proponents source complex can be obtained from the Ministry.

3.2.2 Monitoring Data

For the contaminants listed in Appendix 6, the Ministry will provide air quality monitoring data for representative urban and non-urban areas in Ontario. However the proponent could be required to provide site specific background monitoring data if the Ministry does not have representative emission or monitoring data for the area. This could occur near highways or in areas with large space heating, wood burning or small point source contributions. Monitoring could also be useful for sources emitting into street canyons or for areas with significant fugitive emissions.

If monitoring is required, data would include a range of meteorological conditions covering all seasons in the year. If the emissions from the background sources are variable, air quality measurements would be needed when the emissions were at maximum levels.

3.2.3 Determining Background for Type A and B Modelling

The method for determining background concentrations depends on the type of modelling performed and on the data available.

Type A Modelling: When "worst case" modelling is performed, maximum background air concentrations must be added to the proponents source complex contribution.

(a) If there are no significant point sources, other than the proponents source complex, then maximum background concentrations would be derived from either modelled area source emissions or the maximum monitored concentrations (see Appendix 10). The maximum background values would be for the averaging times of the appropriate air quality standards.

If comparisons are made with hourly average air quality standards, maximum concentrations for stable, neutral or convective conditions could be added to the maximum contribution of the proponents source complex for the same atmospheric stability conditions.

(b) For cases where there are other significant point sources either (i) the Ministry will provide modelled maximum background concentrations due to both significant point and area sources for regions where such data is available; or, (ii) the proponent would do worst case model runs for significant point sources and add these maximum values plus either modelled area sources or monitored uniform background concentrations to the maximum concentration due to the proponents source complex.

Type B Modelling: When detailed multisource modelling is performed, all significant point sources are included in the dispersion model runs. A contiguous hourly meteorological data set is used in this analysis.

(a) If a contiguous time series of background concentrations (modelled area source concentrations or monitoring data) is available these data could be added to the time series of model results for the proponents source complex and other significant point sources. The data set would be analysed to compare the modelled ambient air concentrations with the air quality standard for the appropriate averaging time.

(b) If a time sequence of modelled area source concentrations is not available and monitoring data is not continuous (i.e., at least 70% of a year's data is needed) the proponent must use derived maximum values for background concentrations. These maximum values would be for the appropriate averaging time and could be stratified by the stability class for hourly concentrations.

CHAPTER 4 SIMPLIFIED MODELLING FOR ASSESSMENT OF SOURCE COMPLEXES

Simplified or "worst-case" modelling applies to two types of source complexes. Small source complexes located in regions of relatively good air quality and larger source complexes located in regions where the background concentrations plus "worst case" concentrations for the proponent's plant are less than all air quality standards for the contaminant. The "worst-case" modelling is simplified in the sense that the user need only provide information to describe their sources. Based on this information the modelling package seeks the maximum hourly average downwind concentration for the plausible ranges of atmospheric conditions for each source. For source complexes the results of the "worst-case" modelling may be used directly to assess the impact of the proposed sources on air concentrations of the emitted contaminants in preparation of a proponent's application for Regulatory approval. However, if the proponent does not wish to use the Ministry's "worst-case" methodology for assessing the potential contribution of their source complex to the ambient air concentrations, the proponent may use the full air quality modelling package described in Chapter 5 to assess their sources.

This Chapter describes the use of the simplified or "worst-model" for assessing the maximum probable contribution that contaminant emissions from a source complex may have on local air quality and discusses how this information may be used by a proponent seeking Regulatory approval for their source emissions.

4.1 Applicability for the "Worst-Case" Modelling

"Worst-case" modelling may be used for small source complexes to show that even with conservative assumptions about the combination of sources that air quality standards in the vicinity of the complex will probably be met. Also this simplified model provides a useful tool for those who wish to undertake preliminary assessment of a specific sources or groups of source before proceeding with a full modelling assessment as described in Chapter 5.

Minor source complexes are sources which yield small contributions to ambient air concentrations even under "worst-case" conditions. When a source complex consists of more than one source of a contaminant, the "worst-case" for the plant may be calculated by summing the "worst-case" concentrations for each of the individual sources. This summation can be performed separately for the three atmospheric stability classes calculated in the model (i.e. see Part 2 and 3 of the Document) and the overall maximum selected.

If a proponent's source complex is located in a region where the background concentration is uniformly distributed (i.e. relatively homogeneous area sources or long range transport of the

pollutant) then "worst case" model runs of the proponents source complex are added to background concentrations. If there are other significant point sources within the radius of influence of the proponent's source complex, then these sources must be included in the background. If the proponent can't obtain maximum background values which include the point sources then they must do "worst case" model runs for these significant point sources and add these maximum values to the uniform background contribution and the maximum contribution due to their own source complex. In either case the proponent would assess their sources using the "worst-case" modelling approach and then add this concentration to the maximum background concentration to assess whether the total concentration of the contaminant is less than the standard for all appropriate averaging times.

In addition, users may employ the "worst-case" model to provide a preliminary assessment of any source of interest. This assessment could be performed to estimate the potential maximum contaminant concentrations due to a source, to examine the effect various source parameters have on the maximum concentration or for other applications. For example, the "worst-case" model may be used to estimate the downwind location where the maximum ground level concentration may be found for an elevated source. The "worst case" model could also be used to estimate the maximum downwind distance at which the proponent's source complex could contribute at least 5% of the air quality standard. This gives the radius of influence of the source complex (minimum of 1 km and a maximum of 25 km). Then, this information may be used in the full air quality modelling package to estimate the range of downwind locations to be considered in the full modelling assessment.

4.2 "Worst-Case" Modelling Methodology

To assess the potential impact on local air quality of relatively small source complexes or source complexes located in regions with relatively good air quality, the proponent may use the methods developed by the Ministry for selecting the set of meteorological conditions which will result in the highest hourly average concentration from a specific source. Such weather conditions are referred to as "worst-case" or critical meteorological conditions. The Ministry has prepared this simplified or "worst-case" modelling approach to significantly reduce the modelling effort required to assess the maximum potential air concentration due to the proposed contaminant emissions. This "worst case" modelling approach would screen out sources with small contributions to ambient air quality from having to perform the detailed multisource modelling described in Chapter 5.

Figure 4.1 summarizes the overall structure of the "worst-case" modelling package. The concentration calculations are based on the dispersion models selected for the full modelling package. The determination of the critical, "worst-case" meteorological conditions has been approached by seeking the conditions which would result in the maximum concentration for

each meteorological category (i.e., convective, neutral or stable) and for each source type (i.e., near surface or elevated releases, or releases into a building or structure wake). The only information required to assess the "worst-case" concentration is the specification of the source parameters.

Once the source parameters have been input no further user action is required and the "worst-case" model will proceed to calculate the critical meteorological conditions which result in the highest ground level concentrations for the convective, neutral and stable atmospheric conditions. Generally, the user need not understand the details of the "worst-case" calculation or the scientific and technical aspects of dispersion modelling under various meteorological conditions for different types of sources. However, for interested users, Appendix 8-2 provides a description of the manner in which the critical meteorological parameters are determined and a discussion of the general approach used to calculate the maximum concentration found within the range of user specified receptors located directly downwind from the source under consideration.

DETERMINE THE PLUME PARAMETERS

If not input calculate the source buoyancy and momentum fluxes for use in the plume rise calculations

If the release is in a wake region define the initial cross-wind and vertical spread due to wake turbulence

If the release is an area source define the effective cross-wind spread

Consider in turn each stability category

1 CONVECTIVE CONDITIONS

Search through plausible range of boundary layer heights, Z_i

Calculate the associated upper and lower bounds for the convective velocity scale w^*

Search through the range of plausible wind speeds ($1.2w^*$ to $6w^*$)

Determine the Monin-Obukhov length scale L and the friction velocity u^* but limit L to be $1/2Z_i$ or less

Calculate the plume downwash and plume rise

Determine the effective plume height as the source release height minus downwash plus rise

Compare the effective plume height to the absolute value of L then if it is less than or equal to absolute L the source is a near surface release, otherwise it is an elevated release

For a near surface release the ground level worst case concentration occurs at the closest receptor. Calculate concentration using surface similarity modelling at this location and proceed the next wind speed unless the nearest receptor is very close to the source and views it as an elevated release. In this case continue to the elevated source calculation of concentration

For an elevated release search estimate the fraction of the plume which is still trapped in the boundary layer and calculate the downwind concentration based on this fraction of the emissions. Then search through to input range of downwind receptor locations and calculate concentration using a convective touch-down model at receptors within this range until the maximum concentration is found

Continue the search through the range of wind speeds for the maximum concentration

Continue the search through Z_i for the overall maximum

Report the overall maximum concentration and the associated meteorological parameters and proceed to the next stability category

Figure 4.1 Schematic outline of the "worst case" modelling methodology.

2

NEUTRAL CONDITIONS

Search through the range of plausible wind speed (1.5 - 15 m/s)

Calculate the neutral boundary layer height

Calculate the plume downwash and the terminal plume rise. Then estimate the distance downwind at which terminal rise is reached

If the effective plume height is zero (less than roughness length scale) then the source is a surface release; otherwise, the source is an elevated release.

For a surface release calculate the concentration at the closest input receptor location using a surface similarity model and then proceed to the next wind speed.

For an elevated release search through the range of input receptor location. Calculate the rise if less than the terminal rise

and

determine the fraction of the plume remaining in the boundary layer. Given the plume rise calculate the effective plume height at the receptor location and then calculate the concentration at this site using a Gaussian plume model. Continue to search through the range of receptor locations until the maximum concentration is found.

Continue the search through the range of wind speeds for the maximum concentration

Report the overall maximum concentration and the associated meteorological parameters and proceed to the next stability category

Figure 4.1 Cont'd

3

STABLE CONDITIONS

Search through the range of plausible wind speed (1.5 - 15 m/s)

Calculate the Monin-Obukhov length scale, L , and the friction velocity u^*

Calculate the stable boundary layer height and the atmospheric stability parameter, S , at the source release height.

Calculate the plume downwash and the terminal plume rise. Then estimate the distance downwind at which terminal rise is reached

Calculate the effective plume height as the sum of the release height minus downwash plus plume rise

If the effective plume height is less than or equal to $1/50$ then the source is a near surface release; otherwise, the source is an elevated release.

For a surface release calculate the concentration at the closest input receptor location using a surface similarity model. Then proceed to the next wind speed unless the closest receptor is very near to the source and views the source as a elevated release. In this case proceed to the elevated calculation.

For an elevated release search through the range of input receptor locations. Calculate the rise if less than the terminal rise

and

determine the fraction of the plume remaining in the boundary layer. Given the plume rise calculate the effective plume height at the receptor location and then calculate the concentration at this site using a Gaussian plume model. Continue to search through the range of receptor locations until the maximum concentration is found.

Continue the search through the range of wind speeds for the maximum concentration

Report the overall maximum concentration and the associated meteorological parameters.

END WORST CASE CALCULATIONS

Figure 4.1 Cont'd

When the model calculation is complete the results are presented in a simple form which summarizes for each of the atmospheric stability conditions the "worst-case" concentration found within the specified range of downwind receptor locations along with the associated critical meteorological parameters.

4.3 "Worst-Case" Input Source Parameters

The "worst-case" modelling package requires that the user define the source being assessed by a series of source parameters. The user is referred to Chapter 2 for a complete description of the source parameters which the proponent should have prepared for their site prior to proceeding with a modelling assessment of the impact of source emissions on local air quality.

For the "worst-case" calculation for each source the required input parameters are:

- stack or emission release height (metres)
- source parameters required to calculate buoyancy flux
 - exit gas (efflux) temperature ($^{\circ}\text{Celsius}$)
 - stack diameter (metres)
 - vertical velocity of the efflux (metres/second)
 - or, alternatively, the calculated source buoyancy flux may be specified (m^4/s^3) for a source on or near a structure (for a wake calculation)
- structure height (metres)
- cross-wind structure width (metres)
- terrain effects
 - surface roughness length scale, z_{0s} (metres)
 - terrain complex or simple
- range of downwind receptor locations of interest
 - nearest receptor location (default 10 m)
 - farthest receptor location (default 25 km).

The buoyancy flux of a source may be directly input if the source parameters related to the buoyancy do not adequately describe the source buoyancy flux (e.g., for flares). In these cases a dummy value of -888. is assigned to the exit gas temperature. If the source efflux temperature is equal to the ambient air temperature the source temperature is given a value of -999. In both

of these cases the source vertical momentum flux is then calculated using the input source parameters but the source temperature is assumed equal to the ambient air temperature at the emission release height.

In addition to being located on a building, a source may be considered to be near to a structure in either the upwind, crosswind or downwind directions depending upon the wind direction. If the source stack height is less than twice height of any nearby structure, the users should assess the downwind concentration due to source emissions using either the minimum building width or by doing calculations for at least the eight principle wind directions ranging from north through south to northwest. The user is referred to Chapter 2 and Appendix A for guidelines to determine structure height and cross-wind width, and for dealing with situations where a source is located near several structures.

In general, the default range of downwind receptor locations should be used to assess a source. However, there could be cases where the plant boundary would be considered as the first receptor. The proponent should contact the Ministry if they are not sure of the appropriate first receptor location. Also, for sources located in special settings such as an urban location or complex terrain, the user should consider if the nature of the source setting results in there being potential downwind locations which require special consideration. For example, there may be structures or terrain features which are above the grade level of the source. These special receptor locations (critical receptors) should be considered when assessing the source and each may be input into the model by setting a small range of downwind receptors to bracket the critical site. The model will need to be rerun for each special receptor site.

Source complexes located near a lake shore may be assessed using the "worst-case" modelling package provided the source complex meets the criteria outlined in Section 4.1 for "worst-case" analysis.

The "worst-case" model calculation does not require specification of the emission rates for the various contaminants emitted by the source being considered. Hence, the resultant concentrations are reported in units of micrograms/cubic metre/gram of contaminant emitted per second. To determine the actual concentration for a contaminant the source emits the user would multiply the model result by the contaminant emission rate measured in grams/seconds.

4.4 Application of "Worst-Case" Modelling Results

The simplified or "worst-case" modelling yields for each source the maximum hourly average concentration (per gram of contaminant emitted per second) evaluated for each of the atmospheric stability categories (convective, neutral and stable) and flags the largest overall concentration. In addition, the model reports the critical meteorological conditions for each stability and the location within the range of downwind receptors where the maximum was found in each case.

The proponent may calculate the probable maximum concentrations due to emissions from this source by multiplying the model output by the largest hourly average emission rates for each of the contaminants emitted. If the proponent's source complex consists of more than one source of contaminant emissions the plant "worst-case" hourly average concentration may be estimated by directly adding the maximum concentrations determined for each source for each stability category irrespective of the location or the specific critical meteorological parameters. The largest plant total for each contaminant then may be used to define an upper bound on the maximum hourly average contaminant concentration due to emissions from the source complex. For simplicity this upper bound concentration is referred to as the plant hourly average "worst-case" concentration.

If the sources within a source complex are to be eligible for Regulatory approval it is necessary that the maximum concentrations due to the plant contaminant emissions plus the existing background concentrations not exceed the established air quality standards for any applicable averaging times. Clearly, for contaminants with standards based on hourly averages, the maximum hourly average background concentration may be added to the plant "worst-case" concentration to determine if the local air quality will be acceptable. However, for contaminants with standards based on longer term averages (e.g., 24 hours, 30 days, 1 year) further assumptions must be made to proceed with source assessment using the results of the simplified modelling.

In the case of standards based on averaging periods up to 24 hours the user may use the plant "worst-case" hourly average concentration plus the maximum average background for the appropriate time period to compare with the standard. This approach of using the maximum hourly average concentration to represent an upper bound for the maximum concentration for longer averaging periods is conservative but may not be overly conservative especially for groups of relatively small sources many of which may emit into a building wake.

For contaminants with standards given in terms of 30 day or longer averages the user may also choose to approximate average maximum concentrations due to the source complex emission with the hourly average plant "worst-case" concentration. Then the maximum background concentration for the appropriate averaging period would be added to this plant "worst-case" concentration prior to comparison with the standard. If the user does not wish to use this simplified but extremely conservative approach for estimating longer term averages they may undertake a full, detailed modelling assessment for their source complex. The full modelling package provides for the calculation of concentrations for averaging periods comparable to those used to define the standards. A third alternative would require that the proponent demonstrate through an analysis of meteorological data that the sources in the area only impact any receptor for a fraction of the 30 day or annual average period. This would require substantial analysis to ensure that the worst case is derived.

A proponent may apply for Regulatory approval for proposed sources within the source complex being reviewed without further modelling being required unless special circumstances indicate otherwise if the "worst-case" calculation results in maximum air concentrations which when added to the appropriate maximum background concentrations yield air concentrations which are less than the applicable standard for all averaging periods. Potential special circumstances could include situations where the calculated "worst-case" concentration plus background is very close to 100% of the established air quality standard. In these cases a full modelling assessment may be required.

If the "worst-case" model calculation results in average maximum air concentrations which when added to the appropriate maximum background concentrations exceed the air quality standard the proponent has several options. The proponent may reduce the emissions from their source complex to a point where the "worst-case" modelling indicates the air quality standards will be met. Or, the proponent may proceed directly to assess the source complex using the full modelling package described in Chapter 5 while retaining the option of revising the source complex emissions by adjusting the plant process(es) to reduce emissions or improving the emission control technology. Alternatively, if the background concentration is a limiting factor the proponent may select another site for the facility.

CHAPTER 5 DETAILED DISPERSION MODELLING FOR SOURCE COMPLEX ASSESSMENT

A detailed dispersion modelling assessment of emissions from a source complex takes into account the contribution of each contaminant source to the local air quality under various meteorological conditions. The Ministry has prepared a dispersion modelling package which a proponent may use without a detailed knowledge of air quality models. The range of meteorological conditions considered is determined by an input file of hourly meteorological data based on observations extending over a contiguous period of at least one year. Within the model, the dispersion calculations take into account the relative locations of the sources within the plant complex as well as the type of source (e.g., near surface release, elevated release, a release into a structure wake or an area source). Other sources within the radius of influence of the proponents source complex can also be included in the multisource modelling.

The full, dispersion modelling package calculates the hourly average concentration of the contaminant under consideration. Based on this hourly averaged data it is possible to calculate averages for longer periods of time such as 24 hours, 30 days or 1 year. In addition, averages may be calculated using either an arithmetic or a geometric mean as required for comparison with the appropriate standard.

The model calculations are undertaken for receptor locations specified by the user. This facilitates the evaluation of the impact of emissions from a source complex on air quality at specific critical receptors as well as a receptor network designed to capture maximum concentrations.

A proponent may choose to undertake a full modelling assessment for their source complex if the simplified, "worst-case" modelling results do not indicate that the plant emissions will probably meet the air quality requirements for Regulatory approval. The full modelling package may however be used to assess any source complex.

This modelling package is more complex to use than the simplified or "worst modelling" assessment in three important areas. First the user must provide the model with significantly more input information including the necessary meteorological data and a list of receptor locations in addition to the source data. Second, the actual modelling package considers much more data than the "worst-case" model and, hence, requires more computing resources (e.g. several input data files are required, several output files are generated, more computing time is required, more computer memory temporary storage during the execution of the program is needed). Third, the model output does not automatically generate a estimation of the maximum probable contaminant concentration. It may be necessary to apply the model several times for various sets of receptors to determine a satisfactory estimate of the maximum concentration for a specific averaging period. All of these items require user action. However, they also provide a more flexible modelling package to assist the user in assessing their specific source complex.

This Chapter outlines the modelling techniques used in the full, dispersion modelling package developed by the Ministry and describes the users role in the use of this package to assess their source complex. Included is a discussion of the development of the necessary input information, a summary of the various modelling and output options including selecting specific time period averages, and a guideline for appraising the modelling results. The actual details of the model calculations are given in Part 2 of this Document entitled "Detailed Description of the Full, Multi-Source Air Quality Modelling Techniques for Calculation of Downwind Air Concentrations".

5.1 Detailed Modelling Methodology

The Ministry's detailed modelling package has been developed following review of the current scientific literature. Dispersion models selected for inclusion into the package were chosen based on their applicability to time scales on the order of 30 minutes or longer, their good evaluation with monitoring data and their relative ease of application.

The Ministry's modelling package has been developed for use without requiring a detailed knowledge of the air quality models included in the package; however, for interested users details of the models are given in Part 2 of this Document. A detailed description of the model micrometeorological inputs is included in Part 3 of this Document.

Figure 5.1 shows a schematic outline of the detailed, modelling package identifying the various steps undertaken within the computer code to process the source complex contaminant emissions through the appropriate dispersion model calculations for the meteorological conditions (convective, neutral and stable) and the source types (e.g., near surface, elevated, release into a building wake). Only Tasks 1 and 5 require user action.

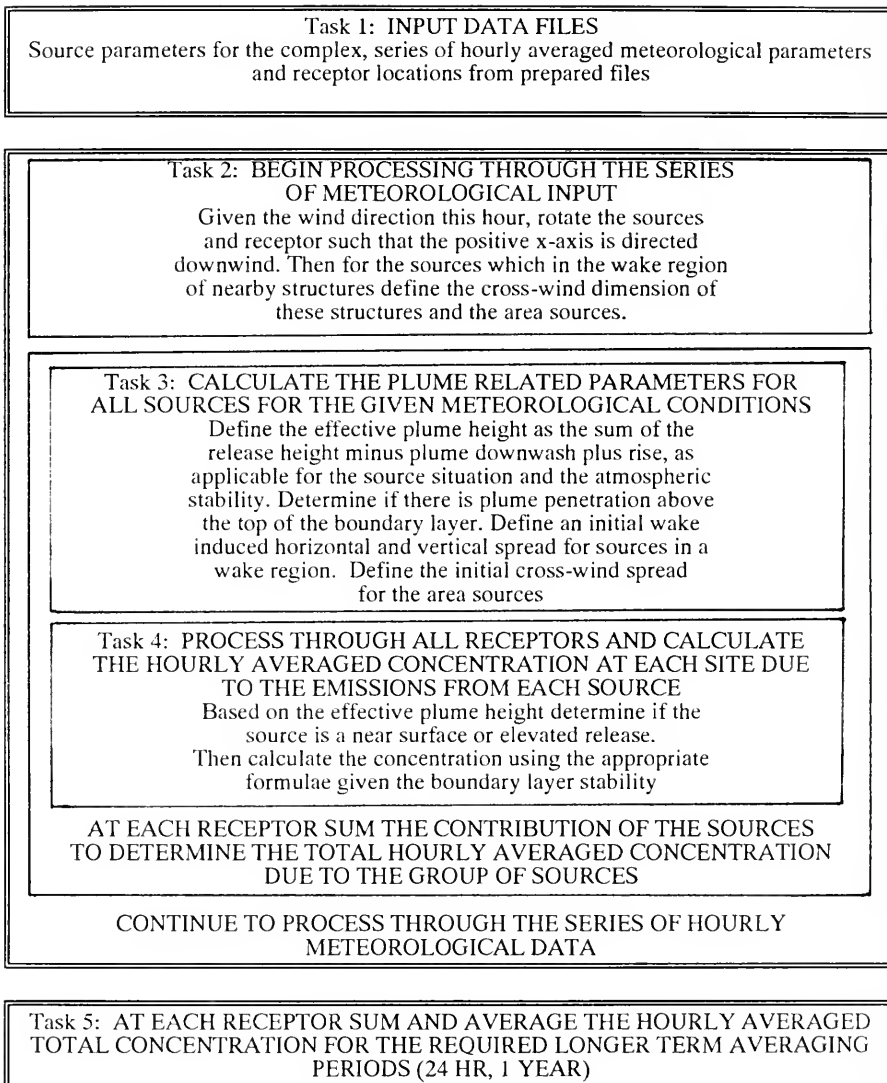


Figure 5.1 Schematic outline of the full multi-source modelling package.

Task 1: Input the Source, Meteorological and Receptor Data

To proceed with detailed modelling the user requires three sets of data: the source parameters for all point sources within the radius of influence of the facility; a meteorological data set which describes the possible atmospheric conditions which could occur at the site under review; and, a list of locations relative to the site location where the models are to calculate contaminant concentrations. The user is responsible for providing the source parameters as described in Chapter 2. The Ministry will prepare meteorological data sets giving regionally representative atmospheric conditions which in most cases may be used directly in the detailed modelling. The exceptions are when the site under review is located near a large lake or in complex terrain. These exceptions are discussed further in Section 5.2.2. The guidelines for determining the list of receptor locations where concentration is to be calculated, the receptor list, are outlined in Section 5.2.3. The model calculations begins with the input of the contaminant emission rates and source parameters for the source complex and the list of receptor locations (often defining a grid of downwind locations). Then the calculations proceed by sequentially reading and processing through each set of hourly averaged meteorological data.

Task 2: Define the Relative Source and Receptor Locations

Within the computer code, the source and receptor coordinates relative to the absolute site location are temporarily redefined for the given input wind direction by rotating them such that the x axis is oriented in the downwind direction and the y axis is oriented in the crosswind direction. This simplifies the subsequent concentration calculations which depend upon the relative downwind and cross wind locations of each receptor with respect to each source. In addition, the steady state plume assumed in the model package results in zero concentrations for receptors upwind from the source complex.

Task 3: Calculate the Plume Related Parameters

For each source emitting into the boundary layer but not into a wake region, the model calculates the plume rise as the maximum of either the plume buoyancy induced rise and the plume momentum induced rise. Then the effective release height of the plume is defined as the sum of the plume rise and the physical release height of the emission minus any stack induce plume downwash during high winds. Based on the effective release height the source is defined as being either a near surface release or an elevated release.

If the source is defined as a near surface release the effective release height is used to determine an upwind pseudo-source location which defines the point at the surface where the emissions would have been released from to have dispersed vertically to a height equal to the effective plume height. For elevated releases the model proceeds to estimate the amount of the plume

material which may rise above the top of the boundary layer. This material is assumed to not contribute to air concentrations within the boundary layer. If applicable, the effective plume height is revised to represent the mean height of the material remaining in the boundary layer.

Included in the meteorological data set for each hour is a flag identifying the stability classification of the atmospheric boundary layer. Based on this stability classification the model selects the method in which plume rise parameters are calculated for each source given the meteorological parameters.

Convective Conditions:

During convective periods the plume buoyancy flux, if it has not been directly input, and the plume vertical momentum flux are calculated using the input ambient air temperature extrapolated to the source release height assuming a dry adiabatic lapse rate. Plume rise due to the buoyancy flux is estimated by assessing the plume buoyancy relative to the strength of the convective downdrafts expressed in terms of the convective boundary layer parameters, w^* and z_i (see Part 3). Rise due to the plume momentum flux is calculated independently, assuming the rise is limited by the ambient mechanically induced turbulence.

If the effective release height of the plume under convective conditions is greater than the absolute value of the Monin-Obukhov length scale (as input in the meteorological data set) the source is defined as an elevated release. If the source is an elevated release the fraction of material penetrating above the top of the boundary layer is estimated by assuming that the boundary layer is capped by a thin stable layer with a lapse rate such that $\Delta\theta$ is 10°C . This stable lapse rate has been based on maximum values from climatological statistics.

Neutral Conditions:

During neutral conditions the plume buoyancy flux, if it has not been directly input, and the plume vertical momentum flux are calculated using the input ambient air temperature extrapolated to the source release height assuming a dry adiabatic lapse rate. Plume rise due to source buoyancy flux and the source momentum flux are calculated independently subject to the assumption that the rise is limited as a result of mixing due to ambient turbulence generated by mechanical shear forces (i.e., due to the wind blowing across a rough surface). These calculations yield an estimate of the final or terminal plume rise. Once the terminal plume rise is determined the downwind location where the plume ceases to rise is estimated.

The source is assumed to be an elevated release if the effective plume height based on the plume's terminal rise is greater than zero (as defined by the surface roughness length scale). For an elevated release the model estimates the amount of plume material which may rise above the

top of the boundary layer. Material located above the top of the boundary layer is assumed to not contribute to air concentrations within the boundary layer. If material is lost from the boundary layer the final effective plume height is reduced to be located at the centre of the remaining material.

Stable Conditions:

During stable periods the plume buoyancy flux, if it has not been directly input, and the plume vertical momentum flux are calculated using the input ambient air temperature extrapolated to the source release height assuming a stable lapse rate calculated from the input meteorological conditions. In the stable boundary layer the terminal buoyant plume rise as limited by ambient atmospheric conditions (i.e., the stable temperature lapse rate) is calculated and compared with the plume rise due to the source momentum flux as limited by mechanically generated turbulence. The maximum of these calculations yields an estimate of the final or terminal plume rise. Once the terminal plume rise is determined the downwind location where the plume ceases to rise is estimated.

The source is assumed to be an elevated release if the effective plume height based on the terminal rise is greater than one-fiftieth of the Monin-Obukhov length scale ($L/50$); otherwise, the source is assumed to be a near surface release. For the elevated releases the model proceeds to estimate the amount of plume material which rises above the top of the boundary layer. Material located above the top of the boundary layer is assumed to not contribute to air concentrations within the boundary layer. If material is lost from the boundary layer the final effective plume height is reduced to be located at the centre of the remaining material.

Emissions into Building Wakes:

In all cases if the source is located on or near a structure and has a release height which is less than twice the structure height the plume is assumed to be released from ground level without rise. Hence, the effective plume height is zero. Then it is assumed that this release is mixed within the building wake prior to dispersing subject to the ambient atmospheric conditions. Hence, the plume is given an initial cross wind and vertical spread which is assumed to be proportional to the cross wind and vertical dimensions of the structure.

For each source released into a wake region the model calculates an upwind pseudo-source location which defines the point at the surface where the emissions would have been released from to have dispersed vertically to a height equal to the wake induced vertical spread. The pseudo-source location is calculated using the appropriate vertical dispersion parameter for the stability classification of the boundary layer.

Releases Above the Boundary Layer:

In general material emitted in the atmosphere above the boundary layer is assumed not to re-enter the boundary layer unless the boundary layer height increases with distance downwind thus entraining air from aloft. The only case where the boundary layer height is assumed to increase is during convective conditions for a lake shore site when the flow is on shore. For these periods, elevated sources emitting above the convective boundary layer are flagged and their contribution to the contaminant concentration at the specified receptors is calculated separately use the lakeshore fumigation model. The results are then added to the contributions of the other sources emitting into boundary layer to determine the total concentration at the receptors during these periods.

Task 4: Calculate Hourly Averaged Concentration at the Receptors

For each set of meteorological parameters, once the plume dependent terms are evaluated, the hourly averaged concentration of the emitted contaminant is calculated at each of the specified receptor locations using the appropriate dispersion calculation for the meteorological conditions (convective, neutral and stable) and the source type (near surface, release into a building wake, elevated). The contribution of each source is evaluated separately and then add together to determine the contaminant concentration due to all of the source complex emissions.

Convective Conditions: Near Surface Releases

The calculation of the concentration due to the near surface release then proceeds with the evaluation of distance from the upwind pseudo-source location to the receptor location expressed as a non-dimensional distance using convective boundary layer scaling. It has been shown during convective periods that the cross-wind integrated concentration is a function of this non-dimensional downwind distance.

Next the vertical plume dispersion parameter, z , and cross wind dispersion parameter, σ_y , are calculated. The vertical plume dispersion parameter, expressed as the mean plume height z is evaluated at the receptor location downwind plus a distance equal to the upwind pseudo-source location while the horizontal dispersion parameter, σ_y , is assumed to be a function of the non-dimensional downwind distance from the source to the receptor. Concentration of the contaminant at the receptor location is then calculated assuming that vertical distribution of the plume material follows an exponential profile and the cross wind distribution is Gaussian (i.e., follows a normal distribution).

For sources where the plume height is less than L , the Monin-Obukhov length, the material is treated as a surface release originating at a pseudo upwind location X_0 . For modelling purposes the source is assumed to appear as an elevated release if the downwind distance from the source to the receptor is less than the upwind distance from the actual source location to the pseudo-source location. In these cases concentrations at the receptors are modelled using the dispersion calculations for an elevated release into a convective boundary layer. Beyond this distance the source is treated as a surface release.

Convective Conditions - Release Into A Wake Region:

Material emitted into a wake is treated as an effective surface release as it is assumed to mix to ground level within the wake region prior to dispersing downwind. Concentrations at downwind receptors due to emissions into a wake are calculated in the same manner used for emissions from a near surface release. The only exception is the evaluation of the cross wind dispersion parameter. When released into a region of structure induced turbulence the plume material is assumed to have an initial cross wind spread which augments the plume spread due to the ambient conditions.

Convective Conditions - Elevated Releases:

The calculation of concentrations due to elevated releases into a convective boundary layer proceeds with the evaluation of the most probable point of impingement of the plume caught in a convective downdraft. The dispersion model assumes that downwind from the source the cross wind integrated concentration of plume material at ground level will be disturbed log-normally around the most probable impingement point. To complete the calculation of the contaminant concentration at the receptor location the plume vertical and cross-wind dispersion parameters are determined as functions of the convectively scaled non-dimensional downwind distance and, then, the ground level concentration is calculated by assuming that plume is normally distributed in the cross-wind direction. If the receptor is not located at ground level the concentration is estimated by assuming that the source release height is effectively less when seen by this receptor. Hence, the receptor is treated as being at ground level and the source release height is reduced by the height of the actual receptor location.

In cases where a fraction of emitted plume material rises above the top of the boundary layer, the concentration is calculated assuming that the hourly averaged emission rate of the source has been effectively reduced by the same amount.

Neutral Conditions - Surface Releases:

The calculation of concentrations due to a surface release during neutral conditions proceeds with the calculation of the vertical and cross-wind dispersion parameters for the plume as a function of the downwind distance to the receptor. The vertical dispersion parameter is expressed as the mean plume height at the receptor location and the dispersion model evaluates the wind speed at this height using a logarithmic vertical wind profile. Then the concentration at the receptor is calculated assuming that in the cross-wind direction the plume is normally distributed and that in the vertical direction the plume has an exponential distribution.

Neutral Conditions - Release Into A Wake Region:

Material emitted into a wake is treated as an effective surface release. Concentrations at downwind receptors due to emissions into a wake are calculated in the same manner used for emissions from a surface release. The only exceptions are the evaluations of the vertical and the cross-wind dispersion parameters. When released into a region of structure induced turbulence the plume material is assumed to have initial vertical and cross-wind spreads. The initial vertical spread of the plume is included in the concentration calculation by evaluating the mean plume height at the downwind distance to the receptor plus a distance equal to the pseudo-source location of the in wake emissions. The effect of the wake induced cross-wind spread of the plume is included in the calculation of concentrations by enhancing the cross-wind plume dispersion parameter.

Neutral Conditions - Elevated Releases:

The calculation of concentration at each downwind receptor due to emissions from an elevated release proceeds with a check on the plume rise. If the receptor is located closer to the source than the distance downwind at which the plume reaches its terminal rise then an intermediate plume rise is calculated using the "2/3 law" for the rise of buoyant plumes (** and the "1/3 law" for momentum driven plumes **). If the rise is less than the terminal value then the other parameters related to plume rise are re-evaluated (the effective plume height and the fraction of plume material which rises above the top of the boundary layer).

The horizontal σ_y and vertical σ_z plume dispersion parameters are calculated as functions of the downwind distance from the source to the receptor. Then the concentration is determined by assuming that the plume material is normally distributed in the cross-wind direction and is normally distributed about the effective plume height in the vertical direction. If a fraction of emitted plume material rises above the top of the boundary layer, the concentration is calculated assuming that the hourly averaged emission rate of the source has been effectively reduced by the same amount

Stable Conditions - Near Surface Releases:

The calculation of concentrations due to a surface release during stable conditions proceeds with the calculation of the vertical and cross-wind dispersion parameters for the plume as functions of the downwind distance to the receptor. The vertical dispersion parameter is expressed as the mean plume height evaluated at the receptor location plus a distance equal to the upwind distance to the pseudo-source location of the release. The dispersion model evaluates the wind speed at this height using a vertical wind profile in the surface layer based on similarity theory. Then this wind speed is used to approximate the mean transport wind for the plume. The horizontal dispersion parameter, σ_y , is assumed to be a function of the downwind distance from the source to the receptor. Then the concentration at the receptor is calculated assuming that in the cross-wind direction the plume is normally distributed and that in the vertical direction the plume has an exponential distribution.

Near surface releases may appear as elevated releases at receptors located very close to the source. For modelling purposes a source is assumed to appear as an elevated release if the downwind distance from the source to the receptor is less than the upwind distance from the actual source location to the pseudo-source location. In these cases concentrations at the receptors are modelled using the dispersion calculations for an elevated release into a stable boundary layer.

Stable Conditions - Release Into A Wake Region:

Material emitted into a wake is treated as an effective surface release as it is assumed to mix to ground level within the wake region prior to dispersing downwind. Concentrations at downwind receptors due to emissions into a wake are calculated in the same manner used for emissions from a near surface release. The only exception is the evaluation of the cross wind dispersion parameter. When released into a region of structure induced turbulence the plume material is assumed to have an initial cross wind spread which augments the plume spread due to the ambient conditions.

Stable Conditions - Elevated Releases:

The calculation of concentration at each downwind receptor due to emissions from an elevated release proceeds with a check on the plume rise. If the receptor is located closer to the source than the distance downwind at which the plume reaches its terminal rise then intermediate plume rise is calculated using the "2/3 law" for the rise of buoyant plumes (** and the "1/3 law" for momentum driven plumes **). If the rise is less than the terminal value then the other parameters related to plume rise are re-evaluated (the effective plume height and the fraction of plume

material which rises above the top of the boundary layer). In addition, if the effective plume height is not greater than $L/50$ (the criterion for a release to be elevated) the source is assessed as a near surface release under stable conditions.

For elevated releases the calculation of concentration proceeds in the same manner as for elevated releases under neutral conditions except that the horizontal (σ_y) and vertical (σ_z) plume dispersion parameters are calculated as functions of the downwind distance and plume height which are appropriate for stable conditions.

Task 5: Prepare the Longer Term Average Concentrations (if required) and Report the Maximum Concentration

Once the concentration has been calculated for the current set of meteorological parameters, subject to the options selected by the user, the modelling package will proceed to determine the current maximum, hourly average concentration and accumulate hourly average concentrations to calculate longer term average concentrations (i.e. 8 hour, 24 hour or longer). In addition, the hourly averaged results may be stored in an output file for subsequent use (e.g., to calculate annual averages or to provide data for graphical analysis). The modelling package then proceeds to consider the next set of meteorological parameters.

Once the modelling package has calculated concentration at the receptor locations for all of the sets of input meteorological parameters, overall maximum hourly averaged concentration at each of the receptor locations may be reported if the user requests. Also, the maximum 24 hour averaged concentration may be calculated. Then the modelling calculations terminate.

5.2 Detailed, Dispersion Modelling Package Input

The detailed or full, multi-source modelling package requires three input data sets: the source parameters for at least the source complex; meteorological information which describes the range of atmospheric conditions for the region of the source complex; and, a list or grid of locations where concentrations are to be calculated. In addition, the detailed modelling package requires some miscellaneous information regarding input and output file names and regarding user selected options for the interim and final output from the modelling calculations. This miscellaneous input is described in the user's guide which accompanies the program codes for the detailed, dispersion modelling package. The required input files are discussed below.

5.2.1 Source Parameters

The proponent is responsible for determining the source parameters which will describe for modelling purposes the source complex being assessed. Chapter 2 describes the source and

plant information which should be prepared by the proponent prior to beginning the dispersion modelling. To create a source data input file which will describe the sources for the detailed model the user must define for each source:

- a source identification (a source number and name)
- the coordinates (x,y) of the source relative to the absolute reference point for the complex
(x, metres east; y, metres north),
- the emissions release height the above grade level of the source complex (metres),
- the source parameters to define the buoyancy and vertical momentum fluxes:
 - stack radius at emission release height (metres),
 - efflux temperature ($^{\circ}$ Kelvin),
 - efflux vertical velocity (metres/second),
 - the contaminant emission rate (grams/second),
 - or the explicitly calculated source buoyancy flux to be used in place of a value calculated using the input source parameters (m^4/s^3),
- the cross-wind width of an area source (metres),
- the height of the structure on which the source is located (metres),
- the location of the corner points of the contiguous structure or structures which could affect the release,
- a value for the local surface roughness length and a description of the terrain as simple or complex (see Chapter 2)

The source buoyancy flux will not be calculated if the input efflux temperature is assigned the dummy value of -888. If the source conditions are such that the efflux temperature is equal to the ambient temperature then the efflux temperature is assign the dummy value of -999. and all subsequent calculations will use the ambient temperature as input in the meteorological data file.

The input contaminant emission rates and source parameters relating to the buoyancy and vertical momentum fluxes should apply to the same plant operating conditions. The source emission rates used in the calculations to determine the maximum contribution of the source complex to local air quality are usually the maximum hourly averaged rates (either currently permitted for existing or anticipated for proposed sources).

Under special circumstances, the proponent, with Ministry approval, may consider groups of sources within the source complex to have variable emission rates due to nature of the plant processes. The Ministry would review any such variable emissions and they would appear as emission limits on the Certificate of Approval.

5.2.2 Meteorological Data for the Site

The Ministry will prepare a series of regionally representative air quality modelling meteorological data sets applicable to different areas of the province. These data sets are based on hourly meteorological observations extending over a contiguous period of one year and have been processed to provide the boundary layer parameters necessary for the dispersion modelling calculations which makeup the full, multi-source modelling package.

In many cases the proponent may simply select the data set which has been designated as representative of the region of their source complex and use it directly in all subsequent applications of the full modelling package to the assessment of their sources. The exceptions are source complexes located in areas where the local setting affects meteorological conditions. Such locales include lakeshore settings and areas where the local topographic features or buildings result in site specific meteorological conditions such as channelled winds. In these cases it is necessary to develop a localized meteorological data set.

Details regarding the development of the regional boundary layer data sets are given in Part 3 of this Document, entitled "Methodology for the Determination of Meteorological Parameters Required For the Full Air Quality Model Calculations". The calculation of the boundary layer meteorological parameters begins with standard, hourly meteorological observations of wind speed, wind direction, temperature and cloud cover. These near surface measurements must have been collected in an acceptable manner such as meet the standards of the Atmospheric Environment Service (AES) of Environment Canada, the Ontario Ministry of the Environment or the World Meteorological Organization and have been quality checked to identify and, if possible, to remove errors in the raw data. Daily or more frequent snow cover information for the meteorological sampling site is also required. In addition, the early morning (1200 GMT) vertical profile of temperature (often referred to as a temperature sounding or upper air data) measured from the ground to 3000 metres is required for the same location as the surface measurements were made. This vertical temperature profile is needed to calculate the height of the convective boundary layer. Hence,

the number of locations where sufficient meteorological data is available for the preparation of regional meteorological data sets is limited to sites where early morning upper air temperature soundings are taken every day. Preparation of regional meteorological data sets should be undertaken by qualified personnel.

Based on the meteorological parameters listed above it is possible to develop the necessary boundary layer meteorological parameters for the detailed model. The calculation of these parameters is undertaken in the meteorological module developed by the Ministry as a pre-processor to the full, dispersion modelling. Details of the method in which the boundary layer parameters are derived from the standard meteorological data are given in Part 3 of this Document. These calculations take into account our current understanding of the atmospheric boundary layer. Stability of the boundary layer is divided into three categories: convective, neutral and stable based on the calculated net heat flux at the surface being positive, essentially zero or negative and on the wind speed.

Once the stability classification of the boundary layer has been determined the appropriate boundary layer parameters are calculated using the near surface meteorological data. To proceed with these calculations it is necessary to define the surface roughness length scale, z_0 , for the site. This value is determined in the manner outlined in Chapter 2. The surface roughness length scale is an important term in the determination of the turbulent state of the atmosphere near the surface.

As noted above, the proponent may need to modify the regional data set for the local conditions. A source complex is considered to be in a lakeshore setting if it is located within 15 km of a major lake. A site is designated as being in a urban setting if it is located within or near (within 1 km) the borders of a concentrated industrial or urban area (population 25,000 or more). Local terrain features may effect the local winds in the area of a source complex if the site is located in a valley or near a hill or ridge. A source complex is considered to be near a terrain feature if the distance between the site and the highest point of the terrain feature is less than twice the largest horizontal dimension of the feature (width or length) to a maximum distance of 15 km.

For each special situation: lakeshore, urban and terrain-dominated the criteria for requiring localization of the regional data set and details of the manner in which the data set is to be modified are given in Appendix A to Part 3 of this Document. The procedures set out for preparing a meteorological data set representative of the conditions at the proponent's site require a series of steps which may include the retrieval and quality checking of raw meteorological data, the preparation and comparison of wind speed and direction statistics, and the re-processing of the raw meteorological data to determine the appropriate local boundary layer parameters. If local upper air data were available the proponent would have the option of using that data. The proponent should ensure that this data set localization is

undertaken by qualified personnel and that all stages of the preparation of the localized data set are documented. All data sets of meteorological parameters which are used in the full, air quality modelling assessment of a source complex are subject to Ministry review and approval.

A proponent has the option of developing their own regional meteorological data set following the guidelines set out in Part 3 of this Document. This option may be of particular interest to the proponent who has available for the area of their site all to the necessary raw meteorological surface and upper air data.

5.2.3 Receptor Locations

The detailed, multi-source dispersion modelling package requires that the user specify the locations where the contaminant concentration is to be calculated. These receptor locations are defined relative to the absolute reference point of the plant. Each receptor is associated with a distance east of the site reference point (x, metres) and a distance north of the site reference point (y, metres). In addition a receptor may be located above the grade level defined for the source complex (z, metres).

If the assessment of air quality due to the emissions from a source complex is limited to specific, critical receptors identified for the area surrounding the site then the modelling is done for these special locations. However, in general the full modelling assessment for a source complex includes the requirement that the maximum concentration due to plant emissions plus the background concentration be determined for each contaminant emitted for each averaging period applicable to the air quality standards for these contaminants. Thus the selection of the receptor locations for a site with more than one source or for a site located in a region where the distribution of the background concentration is non-uniform requires careful consideration. Of course, for hourly maximum concentrations due to sites with a single source in a region of uniform background, the receptors need only be located directly downwind from the source.

To determine maximum concentrations for averaging times of 8 hours or longer or to determine concentrations due to several point sources, the location of the receptors is very important. The distribution and emission strength of the point sources as well as the distribution of background concentrations should be considered.

The number and location of receptors needed to adequately find maximum concentrations depends on the averaging time and on the distribution of the sources. If only an hourly average model result is needed it is possible to orient receptors downwind of the source complex enclosing the paths of the individual sources. However for longer time period averages an extensive fixed grid is needed.

The proponent can begin the assessment by performing "worst case" model runs for the sources on their complex. For each source they should determine the downwind distance and the magnitude of the maximum concentrations. The proponent would also determine the distance to which each source could contribute 5% or more of the air quality standard for that pollutant (the hourly standard would be used if available, otherwise use the shortest averaging time standard).

This information would then define the radius of influence of the proponents source complex. The receptor grid should extend to this radius of influence distance with a maximum radius of 25 km and a minimum radius of 1 km. All point sources which could contribute 5% or more of the air quality standard within the proponents radius of influence should be included in the modelling. Where available the Ministry will provide the necessary local source parameters for sources which are not part of the proponent's complex.

The simplest method for defining a receptor grid would be to use a dense, uniform grid over the radius of influence of the proponent's source complex. Since this could involve a large number of grid points alternative receptor grids might be used.

As an example, the following method might be used to distribute receptor locations. For comparison with air quality standards of 24 hours or less, maximum concentrations would be determined by using an initial coarse grid search followed by a fine grid search around the coarse grids maximum.

1. Using "worst case" model results, identify all point sources with maximum hourly average concentrations within 10% of the single largest source. Use these sources for subsequent analyses.
2. For near surface releases, include a set of receptors as close to the source location as possible. These receptors should encircle the source.
3. For elevated sources, set up a grid centred on the proponent's source complex. Examine the distance to the maximum concentration (X_m) for each of the proponent's elevated sources. Set up a grid which uses a grid spacing of 1/3 (or less) of the maximum value of X_m out to twice the maximum value of X_m (≤ 25 km). The remainder of the grid out to the proponent's radius of influence should use a grid spacing at least as small as this maximum value of X_m .
4. Special receptor locations such as buildings or elevated receptors should be included. If the source complex is located in complex terrain, receptors could have an associated vertical position with respect to the zero grade level defined for the plant.

The selection of receptor locations is adequate if the maximum averaged concentration is determined within $\pm 5\%$ of the standard for the appropriate averaging time.

5.3 Application of Detailed Modelling Results

Once the detailed air quality modelling has been completed for the source complex it is possible for each of the appropriate averaging periods to compare the results of the model calculations of concentration plus the background contaminant concentration with the ambient air standard. If the maximum averaged concentration (including background) is less than the applicable standard then the proponent may proceed to apply for Regulatory approval. Otherwise, the proponent may revise the source complex emissions (by enhancing the emission controls or changing the process to reduce emissions) to a point where the modelling indicates that the air quality standards will be met.

When proceeding for Regulatory approval the proponent should be prepared to document the input used in the detailed modelling calculations as well as the modelling results for each contaminant and appropriate averaging periods including; the maximum averaged concentration due to source emissions presented as the total maximum concentration and as its component values (i.e., the modelling result and the background concentration), and the location of the maximum concentration with respect to the source complex.

APPENDIX A "TECHNIQUES FOR DEFINING BUILDINGS AND STRUCTURES WITHIN OR NEAR THE SOURCE COMPLEX FOR AIR QUALITY MODELLING PURPOSES"

A.1 Definition of Building Height

The height of a building is defined as the maximum height of the building excluding any stacks or vents. If there is a major structure such as a penthouse or tank on the top of the building, the building height, HB, may be taken as the height at the top of this structure.

In the case of a cluster of buildings the height is taken as the height of the tallest building. Buildings are considered to be part of a cluster if the distance between the buildings is equal to or less than the height of the taller structure.

A.2 Definition of the Building Width

Building width refers to the cross-wind dimension of the structure or cluster of buildings. For buildings or clusters without a simple rectangular shape the cross-wind projection of the structure or structures is calculated by drawing an rectangular envelop around them. First draw two parallel lines which are perpendicular to the wind direction and define the front and back of the group of buildings. Then complete the envelope by drawing two lines parallel to the wind direction which define the maximum projection of the structures in the cross-wind direction. The cross-wind width of the structure or cluster is the distance between the lines parallel to the wind.

A.3 Effective Source Location

For modelling purposes sources emitting to a wake region the source is assumed to be effectively located at the centre of the building or cluster of building as defined by the centre of the rectangular envelop outlining the structures for the given wind direction.

APPENDIX B "WORST-CASE" MODELLING METHODOLOGY

This Appendix describes the manner in which the critical meteorological parameters and the maximum concentration are determined by the simplified, "worst-case" model calculations. Details of the actual modelling equations are not given as the model formula are the same as those used in the full model calculations. Those interested in the dispersion model equations will find these in Appendix 8-2 where the details of the full modelling package are presented.

The "worst-case" is simplified in the sense that user need only provide information to describe their sources. Based on this information the modelling package seeks for each source the maximum hourly average concentration for the plausible ranges of atmospheric conditions within a specified range of receptor locations sited directly downwind. The following three Sections of this Appendix discuss the manner in which the critical meteorological parameters and the maximum concentration are derived for each the three categories of atmospheric stability; convective, neutral and stable, respectively.

B.1 "Worst-Case" Modelling for Convective Conditions

Convective meteorological conditions occur principally during daytime periods when there is an absence of snow cover. The important meteorological parameters for modelling pollutant dispersion during convective periods are: the boundary layer (also referred to as the mixed layer) height, z ; the convective velocity scale, w^* , which measures the strength of the convective mixing; and, the wind speed, u . In addition, the determination of concentration for all stability categories is weakly dependent upon the ambient air temperature; however, because the modelling results are relatively insensitive to ambient temperature all "worst-case" model calculations are undertaken for an ambient temperature of 20°C assumed to be measured at 10 metres.

To seek the "worst-case" conditions during convective periods the search begins by stepping through the range of plausible values of the boundary layer height. The minimum plausible value for the mixed layer height is set to be 50 metres based on the assumption that this is the minimum depth required for convective mixing to develop. The maximum plausible value of the convective boundary layer height is assumed to be 3000 metres based on a review of measurements of mixed layer heights collected during several special studies. The range of mixed layer heights is searched by the "worst-case" model using a series of telescoping grids with a final resolution of 10 metres.

Based on the specific mixed layer height, the "worst-case" model estimates a physically reasonable minimum and maximum values of convective velocity scale. The convective velocity scale and the mixed layer height are not independent variables as the ratio z/w^* defines the Lagrangian time scale in the mixed layer (Lilly, 1968). The lower and upper bounds for w^* given z are calculated

using empirical formula derived from the measured data showing w^* plotted as a function of z_i . Figure B-1 shows a graph of the data used and the empirical curves selected to define the lower and upper bounds of w^* .

Review of the dispersion models used to calculate downwind concentration during convective periods indicates that for a near surface release the maximum ground level concentration occurs for the minimum value of w^* , while, for an elevated release the maximum ground level concentration occurs for the maximum value of w^* .

Once a value of w^* has been selected if the conditions are to be convective then the range of plausible wind speeds is $1.2w^*$ and $6w^*$ (metres/second). The range of wind speeds is searched until the "worst-case" value is determined within 0.25 metres/second.

Given a plausible set of values for the convective boundary layer parameters z_i , w^* and u it is possible to determine the two other boundary layer parameters used in the dispersion model calculations of concentration: the Monin-Obukhov length scale, L , and the friction velocity, u' . During convective periods the maximum absolute value of the Monin-Obukhov length scale is limited to one-half z_i which implies that turbulence generated by mechanical shear forces is limit relative to turbulence generated by surface heating. For practical modelling purposes this limit on the convective boundary layer parameters must be applied because for simplicity the inter-dependence of some of the meteorological parameters was determined using only empirical relationships.

Once all of the convective boundary layer parameters used in the dispersion models have been determined it is possible to calculate the maximum concentration within a given range of downwind receptor locations. First, the plume rise is estimated based on the source buoyancy and momentum flux. Then if the source release height plus the plume rise, that is the effective plume height (z_e), is greater than the absolute value of the Monin-Obukhov length scale, L , the source is defined to be an elevated release. Otherwise, the source is considered to be a near surface release. All releases into a building wake are assumed to be surface releases ($z_e = 0$) but with initial vertical and horizontal plume spread induced by the wake turbulence.

If the source is considered to be a near surface release the minimum value of w^* for the given z_i is used to calculate the concentration. First the model calculates the effective upwind location, x_0 , where the source would had to have been released from to have been a surface release which dispersed vertically to a height equal to the effective plume height, z_e , or, in the case of releases into a building wake, which dispersed to a height equal to the initial building induced vertical spread of the plume. However, even near surface releases not emitting into a wake region may appear elevated to receptors which are located very close to the source. For modelling purposes a near surface source is assumed to appear as an elevated release for all receptors located closer to the source than a distance equal to x_0 . In these cases the concentration calculation based on a near surface release is evaluated at the receptor distance equal to x_0 if this distance is greater than the distance to the nearest specified receptor.

The calculation of the concentration due to the near surface release then proceeds with the evaluation of the model parameters: z_e , the mean plume height evaluated at the receptor location plus x_0 ; and, σ_y , the plume horizontal spread which may be enhanced by the initial building wake induced spread. These model parameters are then used to calculate the concentration and the resultant value is compared to the previous maximum concentration calculated under convective conditions. If the current concentration is larger it is retained along with its associated meteorological parameters. If this source has appeared to be elevated for some nearby receptors it is also assessed as an elevated release for this range of downwind locations.

If the source is an elevated release the maximum value of w^* (for the specific z_i) is used to calculate maximum ground level concentration within the range of downwind receptors. First the most probable point of impingement of the plume caught in a convective downdraft is evaluated and the amount of the plume mass trapped in the convective boundary layer is estimated by assuming the boundary layer is capped by a thin stable layer with a stable lapse rate such that $\Delta \theta$ is 10°C . At each downwind receptor the plume horizontal, σ_y , and vertical, σ_z , dispersion parameters are calculated. Then the concentration due to the fraction of the plume trapped within the boundary layer is evaluated. This process is repeated for the range of downwind receptors until the location of the maximum concentration is resolved using a telescoping grid search with a final 10 metre step size. The maximum concentration based on the current set of boundary layer parameters is compared with the previously determined maximum concentration calculated for convective conditions. If the current concentration is larger then is retained as the maximum along with its attendant meteorological parameters.

The search through the ranges of convective boundary layer parameters is continued until all plausible values have been considered. The maximum concentration found is retained along with its associated meteorological parameters for comparison with the maximum concentrations which occur under other stability conditions and for presentation at the end of the "worst-case" model calculations.

B.2 "Worst-Case" Modelling for Neutral Conditions

Neutral boundary layer conditions represent those periods when the atmospheric conditions neither act to enhance or suppress the generation of turbulence by mechanical shear forces. These would be periods when the surface heat flux is essentially zero or when relatively large wind speeds results in mechanically generated turbulence which dominates the turbulent state of the boundary layer.

The important meteorological parameter to be considered during neutral periods is the near surface wind speed. The range of wind speeds searched by the "worst-case" model extends from 1.5 metres/second to 15 metres/second. The minimum value of 1.5 metres/second has been selected based on the inherent assumption of steady state conditions within all of the dispersion models used in the "worst-case" calculations where it is assumed that plume downwind transport is dominated by advection (by the wind) and that diffusion in the along wind direction may be ignored. If the

wind speed is very small or conditions are calm this assumption is no longer valid. The absence of a simple model to treat calm conditions is recognized as a limitation in both the "worst-case" and full modelling package. The upper limit for the wind speed searched has been set at 15 metres/second based on a review of near surface (10 metre) wind speed statistics. Generally, a persistent wind speed exceeding 15 m/s for a period of an hour occurs infrequently. In addition, as wind speed increases so does mechanically generated turbulence leading to increased plume mixing with the ambient air resulting in greater dilution of the contaminant concentration. Hence, the maximum concentration is not generally expected to occur for the maximum wind speed.

To seek the maximum concentration under neutral conditions the range of plausible wind speeds is searched using telescoping grids with a final resolution of 0.25 m/s. For each value of wind speed the friction velocity, u^* , is calculated and the boundary layer height estimated. The plume rise as limited by mechanically generated turbulence is calculated and the fraction of the plume mass which has not risen above the boundary is estimated. If the release has no plume rise and has been essentially released at the surface, or if the release has been into a building wake then the source is a surface release. Otherwise the source is an elevated release.

If the source is a surface release the concentration is evaluated at the nearest specified receptor. The model parameters: x_0 , the pseudo-source location for a release into a wake with an initial wake induce vertical spread; z , the mean plume height evaluated at the receptor location plus x_0 ; u , the mean wind speed at plume height z ; and, σ_y , the horizontal dispersion parameter enhanced by wake induced spread if applicable are evaluated. Then the concentration is determined from the model parameters and compared with the previous maximum concentration evaluated for neutral conditions. If the current concentration is larger it is retained along with its associated meteorological conditions.

If the source is elevated it is necessary to search through the range of downwind receptor locations specified by the user to find the maximum concentration for the given range of distances. This search is undertaken using telescoping grid searches with a final resolution of 10 metres. At each downwind location the current plume rise is calculated along with the fraction of plume mass which remains in the boundary layer. Then the effective plume height (which is generally the sum of the plume release height and the rise) and the horizontal (σ_y) and vertical (σ_z) plume dispersion parameters are calculated. Based on the model parameters the concentration of the material remaining in the boundary layer is calculated at the receptor location. The range of downwind receptors is searched until the maximum concentration for the current wind speed is found. This concentration is compared with the previous maximum found and if it is larger it is saved along with its attendant meteorological parameters.

The search for the largest concentration under neutral conditions is continued until the maximum concentration for the range of plausible wind speeds has been found. This value is retained for comparison with the maximum concentration determined for other meteorological conditions and for presentation at the end of the "worst-case" calculation.

B.3 "Worst-Case" Modelling for Stable Conditions

Stable conditions occur at night or during the winter when the ground is snow covered. During these periods the ambient atmospheric conditions act to damp turbulence in the boundary layer. The important meteorological parameter for modeling dispersion in the stable boundary layer is the near surface wind speed, u . To determine the largest concentration due to emissions during stable periods the range of wind speeds from 1.5 to 15 metres/second is searched using telescoping grids with a final resolution of 0.25 metres/second. For each value of the wind speed the Monin-Obukhov length scale, L , and the friction velocity are calculated using an empirical relationship between L and u . Then the boundary layer height is estimated using L and u . Using an analytical surface similarity relation for the vertical temperature gradient, it is also possible to estimate the atmospheric stability parameter, S , as a function of L and u . The parameter S is the Brunt-Vaisala frequency squared and is a measure of ambient stability.

Based on the stable boundary layer parameters it is possible to estimate the upper limit to the plume rise and the fraction of the plume mass which does not rise above the top of the stable boundary layer. Material which rises above the boundary layer is assumed not to re-enter the boundary layer unless the boundary layer height increases thus entraining air from aloft. The dispersion models used for the "worst-case" calculations are based on the assumption of a steady state boundary layer where the height is constant for the modelling period (one hour). Hence, material which rises out of the boundary layer is assumed to not contribute to the hourly average concentration.

If the effective release height for the source as defined by the sum of the source height and the plume rise is less than or equal to $L/50$ then the source is described as a near surface release. Otherwise, the source is an elevated release. All releases into a building wake are assumed to be surface releases ($z_e = 0$) but with initial vertical and horizontal spread of the plume induced by the wake turbulence.

If the source is considered to be a near surface release the model calculates the effective upwind location, x_0 , where the source would have to have been released from to have been a surface release which dispersed vertically to a height equal to the effective plume height, z_e , or, in the case of releases into a building wake, which dispersed to a height equal to the initial building induced vertical spread of the plume. However, near surface releases not emitting into a wake region may appear elevated to receptors which are located very close to the source. For modelling purposes a near surface source is assumed to appear as an elevated release for all receptors located closer to

the source than a distance equal to x_0 . In these cases the concentration calculation based on a near surface release is evaluated at the receptor distance equal to x_0 if this distance is greater than the distance to the nearest specified receptor.

The calculation of the concentration due to the near surface release then proceeds with the evaluation of the model parameters: z , the mean plume height evaluated at the receptor location plus x_0 ; and, σ_y , the plume horizontal spread which may be enhanced by the initial building wake induced spread. These model parameters are then used to calculate the concentration and the resultant value is compared to the previous maximum concentration calculated for stable conditions. If the current concentration is larger it is retained along with its associated meteorological parameters. If this source has appeared to be elevated for some nearby receptors it is also assessed as an elevated release for this range of downwind locations.

If the source is elevated it is necessary to search through the range of downwind receptor locations specified by the user to find the maximum concentration for the given range of distances. This search is undertaken using telescoping grid searches with a final resolution of 10 metres. At each downwind location the current plume rise is calculated along with the fraction of plume mass which remains in the boundary layer. Then the effect plume height (which is generally the sum of the plume release height and the rise) and the horizontal (σ_y) and vertical (σ_z) plume dispersion parameters are calculated. Based on the model parameters the concentration of the material remaining in the boundary layer is calculated at the receptor location. The range of downwind receptors is searched until the maximum concentration for the current wind speed is found. This concentration is compared with the previous maximum found and if it is larger it is saved along with its attendant meteorological parameters.

The search for the maximum concentration under stable conditions is continued until the largest concentration for the range of plausible wind speeds has been found. This value is retained for comparison with the maximum concentration determined for other meteorological conditions and for presentation at the end of the "worst-case" calculation.

APPENDIX 8-2

DETAILED DESCRIPTION OF THE FULL MULTI-SOURCE AIR QUALITY MODELLING TECHNIQUE FOR CALCULATION OF LOCAL AIR CONCENTRATIONS

AIR QUALITY MODELLING DOCUMENT PART 2

TABLE OF CONTENTS

Forward	2-i
Table of Contents	2-ii
1. OVERVIEW OF THE FULL DISPERSION	2-1
MODELLING PACKAGE	
1.1 Introduction	2-1
1.2 Meteorological Situations Considered	2-1
1.3 Source Situations Considered	2-6
1.3.1 Simple Source Situations	2-6
1.3.2 Special Source Situations	2-6
1.3.2.1 Lakeshore Settings	2-6
1.3.2.2 Complex Terrain	2-7
1.3.2.3 Source Located On or Near Building	2-8
1.4 The Full Modelling Package	2-8
2. DETERMINATION OF THE NECESSARY	2-9
BOUNDARY LAYER PARAMETERS	
2.1 The Required Meteorological Information	2-9
2.2 Determination of the Boundary Layer	2-14
Parameters	
2.2.1 Convective Conditions	2-14
2.2.2 Neutral Conditions	2-16
2.2.3 Stable Conditions	2-16
3. DETERMINATION OF THE EFFECTIVE PLUME	2-18
HEIGHT	
3.1 Influence of the Source Situation on	2-18
the Release	
3.1.1 Releases into a Structure Wake	2-18
3.1.2 Releases in Complex Terrain	2-20
3.1.3 Area Sources	2-20
3.1.4 Downwash of Emissions Released	2-21
Outside a Wake Region	

3.2 Plume Rise	2-21
3.2.1 Evaluation of the Momentum and Buoyancy Flux	2-22
3.2.1.1 Special Considerations for the Determination of Source Fluxes	2-23
3.2.2 Momentum Induced Plume Rise	2-24
3.2.3 Buoyancy Induced Plume Rise	2-24
3.2.3.1 Convective Conditions	2-24
3.2.3.2 Neutral Conditions	2-24
3.2.3.3 Stable Conditions	2-25
3.2.4 Moist Plume Rise	2-25
3.3 Calculation of the Effective Plume Height	2-26
3.3.1 Effective Plume Height in Complex Terrain	2-27
3.4 Plume Penetration Above the Boundary Layer	2-27
3.4.1 Convective Conditions	2-28
3.4.2 Neutral Conditions	2-29
3.4.3 Stable Conditions	2-29
4. CALCULATION OF DOWNWIND CONCENTRATION	2-30
4.1 Convective Meteorological Conditions	2-30
4.1.1 Near Surface Releases	2-30
4.1.2 Elevated Releases	2-32
4.2 Neutral Meteorological Conditions	2-33
4.2.1 Near Surface Releases	2-33
4.2.2 Elevated Releases	2-35
4.3 Stable Meteorological Conditions	2-35
4.3.1 Near Surface Releases	2-36
4.3.2 Elevated Release	2-37
GLOSSARY OF SYMBOLS	2-39
REFERENCES	2-43
APPENDIX A: MODELLING AIR QUALITY DUE TO CONTAMINANT RELEASES FROM A LOCATION ON OR NEAR A BUILDING	2-46
APPENDIX B: DETERMINATION OF FLARE BUOYANCY FLUX AND FLAME LENGTH	2-54

APPENDIX C: MODELLING AIR QUALITY FOR RELEASES	2-56
IN A LAKESHORE SETTING	
APPENDIX D: A GUIDELINE FOR PHYSICAL MODELLING	2-64
OF SOURCES IN COMPLEX SETTINGS	

CHAPTER 1

OVERVIEW OF THE FULL DISPERSION MODELLING PACKAGE

To maintain satisfactory air quality it is necessary to regulate current and future contaminant emissions such that when the ambient air quality is determined it does not exceed the established air quality standards. Evidence of the probable attainment of satisfactory air quality will generally be obtained through dispersion modelling.

1.1 Introduction

The Ministry has developed a dispersion modelling package designed to assist in the assessment of ambient air quality due to existing and proposed emission sources. This Part of the Air Quality Modelling Document describes in detailed the air quality models which have been selected based on a review of the recent scientific literature. In general, this review covered all types of short range models (e.g. Gaussian plume models, grid point models etc.) applicable for averaging times on the order of 30 minutes and greater. Models selected for inclusion in this modelling package are classified according to the meteorological conditions and the source situation. The models described are for continuous releases of non-reactive contaminants.

1.2 Meteorological Situations Considered

Several short range modelling techniques have been selected to satisfy the various meteorological conditions and site situations which are routinely encountered. These are summarized in Tables 1.1a and 1.1b. Figure 1.1 shows a sketch of the evolution of the planetary boundary layer relative to the surface heat flux. Three general boundary layer meteorological grouping are made based largely on the value of the surface heat flux.

Periods when the surface heat flux is positive are referred to as convective. During convective conditions (also referred to as unstable conditions) the air in the planetary boundary layer is well mixed due, principally, to large eddies generated by surface heating from incoming sunlight.

Table 1.1a

Short Range Modelling Methods for Average Air Concentrations
from Continuously Emitting Sources

Part 1: Basic Modelling Package for Sources in Simple Situations

METEOROLOGY CONDITIONS	SIMPLE SITUATIONS		
	NEAR SURFACE	ELEVATED	VERY TALL STACKS
CONVECTIVE	SURFACE		CONVECTIVE SCALING
NEUTRAL	SIMILARITY	REVISED	GAUSSIAN
STABLE	MODELLING		

Table 1.1b

Short Range Modelling Methods for Average Air Concentrations
from Continuously Emitting Sources

Part 2: Special Situations

LAKESHORE SETTING	COMPLEX TERRAIN	BUILDING WAKES
FUMIGATION MODEL	CASE BY CASE CONSIDERATIONS (MAY REQUIRE PHYSICAL MODELLING)	WAKE RECIRCULATION TO GROUND AND ENHANCED DISPERSION BASED ON BUILDING DIMENSIONS

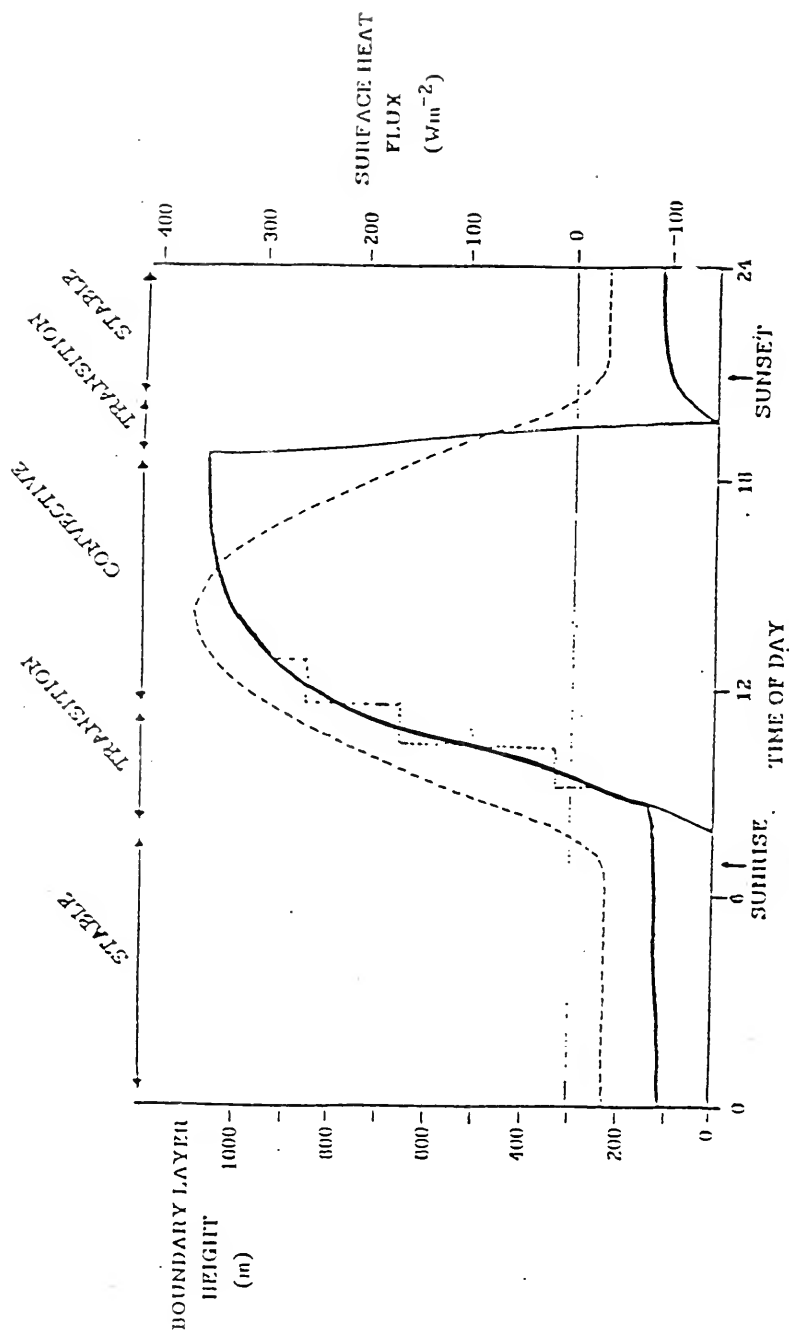


Figure 1.1

Schematic diagram of the evolution of the planetary boundary layer and of the surface heat flux sketched as functions of the time of day. The left axis shows the scale of the boundary layer height, z_i . The right axis presents the scale of the surface heat flux, H_0 . The dark solid line denotes the height of the boundary layer. The dotted line shows a stepwise steady state approximation to the boundary layer height applied during transition periods. The surface heat flux is plotted using a dashed line.

Stable conditions refer to periods when the surface heat flux is negative (i.e., from the air to the ground). During these times mixing in the planetary boundary layer is very small and the ambient atmospheric conditions act to dampen any fluctuations in the flow (turbulence). Stable conditions occur at night or during winter when the ground is snow covered.

When the surface heat flux is essentially zero the atmosphere is neither stable nor convective. These periods are treated as neutral. Within this modelling package neutral stability refers to periods when the atmospheric conditions neither act to enhance nor to suppress the generation of turbulence.

Periods of changing conditions referred to as transition periods usually do not persist but may be associated with events such as sunrise and sunset. During transition the boundary layer flow is not steady and can change continuously. In this report, the boundary layer during transition periods will be assumed for modelling purposes to be steady and to change only in a stepwise manner. The exception is the spatial transition from a stable marine boundary layer to a convective boundary layer over land. This case is considered as a special modelling situation for sources located near the lakeshore.

During periods when the wind speed exceeds approximately six meters per second the turbulence generated by mechanical shear forces may dominate the turbulent state of the atmosphere. Hence, very windy conditions can affect the stability of the atmosphere. In the modelling package, windy periods will be considered to be neutral.

The planetary boundary layer is the region of the atmosphere nearest the ground which is directly influenced by the presence of the surface. Under stable conditions this layer may be very shallow (less than 100 meters deep) and is influenced principally by surface friction. Under convective conditions the boundary layer may be deeper than 2 kilometres depending upon the amount of heating available to drive the deep convective mixing. The height of the planetary boundary may change significantly when the surface heat flux increases or decreases. For modelling purposes, the height of the boundary layer will be assumed to be constant over the averaging period of an hour. Hence, the temporal evolution of the boundary layer height will be treated as a stepwise steady state as shown in Figure 1.1.

1.3 Source Situations Considered

The source situation also influences the modelling approach selected. When located away from structure wakes and over gently rolling terrain, the sources are classified according to the height of the emissions (the effective stack height, z_e) with respect to the planetary boundary layer height. In these cases the height of the planetary layer is assumed to be horizontally homogeneous. In addition, sources located in special settings such as in complex terrain or near a lakeshore or in building wakes may require specific modelling.

1.3.1 Simple Source Situations

In the case of sources located in simple settings, three modelling techniques are used. For sources emitting near ground level surface similarity modelling techniques are employed. Surface similarity modelling is based on experimental evidence which supports the theory that the average behaviour of the flow (including pollutant dispersion) near the ground may be described by general formulae which depend upon only a limited number of parameters to characterize the flow. For tall stacks under convective conditions convective scaling is used. Gaussian dispersion modelling is used under neutral and stable atmospheric conditions for elevated and very tall stacks; however, the model parameters for the Gaussian probability distribution calculation have been revised to employ recent knowledge of the atmospheric boundary layer.

Area and line sources are treated using the point source surface similarity calculation and assuming an initial spread proportional to the cross-wind dimension of the source.

1.3.2 Special Source Situations

Three special source situations also have been reviewed; lakeshore settings, complex terrain, and settings where the presence of buildings and structures affects the contaminant dispersion.

1.3.2.1 Lakeshore Settings

During convective periods assessment of sources located in a lakeshore setting, defined as sites within 15 km of a major lake, may require a somewhat different modelling approach. Over the lake the boundary layer may be very shallow ($\approx 50 - 100$ metres) while inland the boundary may be very deep. At the lakeshore the spatial inhomogeneity in the boundary

layer height must be considered when modelling sources in this type of setting. A shoreline fumigation model is used in these cases.

Appendix C details the fumigation model of Misra (1980) used in the Ministry's modelling package.

1.3.2.2 Complex Terrain

Sources located in complex terrain or near significant topographic features will need special consideration due to the expected site dependency of pollutant dispersion in these regions. Terrain features are considered to be sufficiently complex to warrant physical modelling if both the following conditions are met.

1. The release height of the contaminant is less than two times the maximum terrain height. The maximum terrain height is defined as the difference between the highest elevation (including tree tops) and the lowest elevation within a distance equal to 20 times the stack height or one kilometre, whichever is greater.
2. The gradient of the terrain height with distance, Δx , from the source is greater than $1/5$.

Appendix D discusses physical modelling of releases in complex settings.

Terrain features can effect the range and frequency of local meteorological conditions and these local changes should be included in the meteorological data used in the model calculations. A detailed discussion of the consideration of local effects in the development of a meteorological data set is given in Part 3 of this Document.

The complex terrain may also influence the dispersion of a plume. Physical modelling may be required to accurately assess concentrations at a complex site. To include within the modelling package a method for assessing releases in a region of complex terrain it is assumed that plume height is equal to half of the plume height calculated for flat terrain. In addition, the location of sites downwind where concentration is calculated (the receptors) must include consideration of their height with respect to the grade level at the source.

1.3.2.3 Sources Located On or Near a Building

Pollutant dispersion from sources located on or near a building(s) may be influenced by the changes in the air flow forced by the presence of the structure(s). The degree to which dispersion is affected will depend upon the meteorological conditions and the relative proximity of the source to the building. When emissions enter the building wake their dispersion will depend upon the details of the wake flow pattern.

The influence of structure wakes on dispersion of emissions from sources located on or near the obstacles is included empirically in the model calculations by enhancing the initial dispersion of the pollutants and reducing the source height for the effluent entering the region of wake downwash. Appendix A discusses in detail the manner in which the influence of building wakes are included in the modelling package.

The details of dispersion from sources located on or nearby obstacles of various shapes can be very complex. Only extensive field tests or wind tunnel experiments can provide a detailed assessment of a specific complex site. Appendix D discusses physical modelling for complex situations.

1.4 The Full Modelling Package

A detailed description of the full, multi-source dispersion modelling package for simple sites is presented in the following three chapters. Chapter 2 outlines the methods for determining the necessary boundary layer parameters with details given in Part 3 of the Air Quality Modelling Document. Next, the calculation of the effective plume release height, which includes consideration of the source situation, the plume rise and the estimation of the potential penetration of the plume above the boundary layer, is described in Chapter 3. It is assumed that the portion of the pollutant emitted into the region above the boundary layer does not contribute to the local air concentration of the contaminant in the boundary layer.

The Chapter 4 describes the methods used for calculating air concentrations of contaminants at downwind receptor locations due to emissions of non-reactive gases. The modelling techniques detailed are for continuous releases from point sources. Line and area sources are considered as points sources with initial spread of the released material proportional to the cross-wind dimension of the source.

CHAPTER 2

DETERMINATION OF THE NECESSARY BOUNDARY LAYER PARAMETERS

The routine application of air quality models in the Ministry's modelling package requires that the information needed to perform model calculations be readily available. First the required meteorological input information will be described and then methods for determining the necessary boundary layer parameters are outlined. Details of the methodology for developing the meteorological data required by the full, multi-source dispersion modelling package are presented in Part 3 of the Air Quality Modelling Document.

2.1 The Required Meteorological Information

The Table 2.1 summarizes the necessary meteorological data needed in the dispersion modelling package or required to calculate the boundary layer parameters used in the modelling package.

The basic meteorological data used by the models are: H_0 , the net surface heat flux, which for this modelling package is calculated based on the location of the meteorological site, the cloud cover, cc , as a fraction of the total sky and the ground snow cover, sc ; the near surface wind speed, u , and direction; the near surface temperature, T_a ; the surface roughness length, z_0 ; the convective boundary layer height, z_i ; and, if available, an elevated wind speed and direction measured close to the elevated source release height.

The surface roughness length, z_0 , may be approximated as 1/30th of the height of the roughness elements such as buildings or trees. Table 2.2 lists z_0 for various surfaces.

Given the location (latitude and longitude) of the meteorological site and the date and time period of interest, the surface heat flux H_0 may be calculated based on the assumption that it is proportional to the net solar radiation plus a small correction for the long wavelength loss of heat from the surface. Cloud cover reduces the net solar radiation reaching the

Table 2.1
Summary of Required Meteorological Information

i) surface heat flux H_0

$H_0 > 5 \text{ W/m}^2$ Convective		$H_0 \approx 0$ Neutral		$H_0 < -5 \text{ W/m}^2$ Stable	
ii)	near surface wind speed, u , and direction measured at approximately 10 metres	ii)	near surface wind speed, u , and direction measured at approximately 10 metres	ii)	near surface wind speed, u , and direction measured at approximately 10 metres
iii)	surface temperature T_a (screen level at approximately 2 metres)	iii)	surface temperature T_a (screen level at approximately 2 metres)	iii)	surface temperature T_a (screen level at approximately 2 metres)
iv)	surface roughness length scale z_0	iv)	surface roughness length scale z_0	iv)	surface roughness length scale z_0
v)	boundary layer height z_1	v)	(optional) elevated wind speed, u_e , and direction plus the height of the measurement	v)	(optional) elevated wind speed, u_e , and direction plus the height of the measurement
vi)	(optional) elevated wind speed, u_e , and direction plus the height of the measurement				

Table 2.2
Roughness Lengths in Centimetres for Various Surfaces

Surface	z_0
Very smooth (ice, mud flats)	0.001
Snow	0.005
Smooth sea	0.02
Lawn, grass up to 1 cm high	0.03
Lawn, grass up to 5 cm high	1–2
Lawn, grass up to 50 cm high	4–9
Fully grown root crops	14
Forest	50
Urban core	100

After Pasquill (1974) and Seinfeld (1975).

Table 2.3
Cloud Cover Reduction Factors for
Incoming Solar Radiation

Sky Cover Percent	Octants (cc)	β
0.0	0	1.00
12.5	1	0.89
25.0	2	0.81
37.5	3	0.76
50.0	4	0.72
62.5	5	0.67
75.0	6	0.59
87.5	7	0.45
100.0	8	0.23

After Maul (1982).

surface and, also, decreases the long wave losses. The calculations follow the formulation reported by Maul (1982):

$$H_o = \alpha R + H_L, \quad (2.1.1)$$

where R is the incoming solar radiation in watts per square metre, H_L is the long wave loss and α is a function of the surface type.

The incoming solar radiation depends on the time of day (t in decimal hours Greenwich Mean Time, GMT), the latitude of the source (L_R in radians), the longitude of the source (L_D in degrees), the day of year (d given as the Julian day, numbers 1 to 365 or 366) and the fractional cloud cover of the sky (cc in number of eighths).

$$R = 950 \beta (\cos(\phi) \cos(\tau) \cos(L_R) + \sin(\phi) \sin(L_R)), \quad (2.1.2)$$

where

$$\tau = \pi(t - t_n)/12 \quad (2.1.3)$$

and

$$t_n = 12 + L_D/15 \quad (2.1.4)$$

is the local noon time (GMT),

$$\phi = \text{ARCTAN}(0.4348 \sin(\pi(d-78)/180)). \quad (2.1.5)$$

β is the radiation reduction factor for the incoming solar radiation due to cloud cover. Table 2.3 lists β for given amounts of cloud cover (sky cover).

This calculation only applies between local sunrise and sunset, that is, for values of t between

$$t_{\text{rise}} = t_n - \frac{12}{\pi} (\cos^{-1}(\tan(\phi) \tan(L_R))) \quad (2.1.6)$$

and

$$t_{\text{set}} = t_n + \frac{12}{\pi} (\cos^{-1}(\tan(\phi) \tan(L_R))). \quad (2.1.7)$$

The factor α is a function of the local surface (a value of $\alpha = 0.35$ is assumed in the modelling typical of rural lands) and is an empirical proportionality factor between the incoming solar radiation and the surface heat flux. Note that when there is snow cover it is assumed that $\alpha = 0$.

$$H_L = -3 (8.5 - cc) \quad (2.1.8)$$

is the long wavelength heat loss at the surface.

Alternatively, H_o may be determined from measurements of net solar radiation or surface fluxes.

The convective boundary layer height, z_i , may be estimated for periods when $H_o > 5 \text{ W/m}^2$ using the vertical temperature versus height profiles obtained from the 1200 GMT radiosonde launch from the meteorological site. Following the method of Holzworth (1967), z_i is calculated as the height above the ground at which the dry adiabatic extrapolation of the surface level temperature, T_a , intersects the (700 EST) vertical temperature profile.

When boundary layer conditions are neutral ($H_o \approx 0$) or stable ($H_o < -5 \text{ W/m}^2$) the boundary layer height is calculated based on the input near surface wind speed. The wind blowing over the surface roughness elements (represented by the roughness scale z_o) generates mechanical turbulence which controls the depth of the neutral and stable boundary layers.

The near surface (anemometer level, z_a) wind speed, u (ms^{-1}), wind direction and the screen level temperature, T_a ($^{\circ}\text{K}$), may be obtained from measurements taken at Environment Canada, Ontario Ministry of the Environment or other meteorological monitoring stations operated in an acceptable manner. The input wind direct is assumed to be measured in 10 degree intervals. Within each of these intervals it is assumed that the direction may have any random value, hence, a random angle within the interval is selected and a specific wind direction based on this randomization is defined for that particular hour.

If wind speed and direction are available from measurements on a meteorological tower at a height close to the elevated source release height then this information may be included in the meteorological data file. This data will be used when calculating the advection of the material from the elevated release.

2.2 Determination of the Necessary Boundary Layer Parameters

The required boundary layer parameters which are to be calculated based on the input meteorological data are summarized in Table 2.4 according the stability category of the boundary layer.

Table 2.4
Required Boundary Layer Parameters

Convective		Neutral		Stable	
i)	friction velocity, u_*	i)	friction velocity, u_*	i)	friction velocity, u_*
ii)	Monin—Obukhov length scale, L	ii)	neutral boundary layer height, H	ii)	Monin—Obukhov length scale, L
iii)	convective velocity scale, w_*			iii)	stable boundary layer height, H

2.2.1 Convective Conditions

It is assumed that when the surface heat flux is greater than 5 Wm^{-2} the boundary layer conditions are convective. The convective boundary layer parameters required in the continuous source models are: the convective scaling velocity,

$$w_* = (g H_o z_i / (\rho c_p T))^{1/3}; \quad (2.2.1)$$

the Monin—Obukhov length scale,

$$L = -u_*^3 T \rho c_p / (g \kappa H_o); \quad (2.2.2)$$

and the friction velocity,

$$u_* = \kappa u / (\ln(z_a/z_o) - \Phi(z_a/L)), \quad (2.2.3)$$

where

$$\Phi(z_a/L) = 2 \ln((1+q)/2) + \ln((1+q^2)/2) - 2 \text{ ARCTAN}(q) + \pi/2 \quad (2.2.4)$$

and

$$q = (1 - 15 z_a/L)^{1/4}. \quad (2.2.5)$$

T is the mean boundary layer temperature and is calculated from the near surface temperature, T_a , the boundary layer depth, z_i , and by assuming the temperature lapse rate in the convective boundary layer is approximately adiabatic, hence,

$$T = (T_a - 0.0098 z_i / 2). \quad (2.2.6)$$

ρ is the density of air (assumed to be approximately 1.2 kg/m^3), c_p is the specific heat of dry air at constant pressure ($c_p = 1005 \text{ J/kg}^\circ\text{K}$), and g is the acceleration due to gravity (assumed to be 9.80665 ms^{-2}). The von Karman constant, κ , is set to 0.35. z_a is the near surface wind sampling height (usually 10 metres).

It is noted that the height of the convective boundary layer has been determined in a manner which is not completely consistent with the above calculation of the convective boundary layer parameters. Thus, in some cases the value of z_i is smaller than the value of L would indicate.

When the surface heat flux is greater than 20 Wm^{-2} it is assumed that value of L is representative of the boundary layer conditions. For cases when the value of z_i is calculated to be less than $|2L|$ the convective boundary layer height is increased to a value equal to two times the absolute value of the Monin–Obukhov length scale. When the surface heat flux is equal to or less than 20 Wm^{-2} it is assumed that z_i is representative of the convective boundary layer and if necessary $|L|$ is reduced to a value equal to one-half of z_i . The minimum value of z_i is limited to 50 metres in non-urban areas and 100 metres in urban areas. Then the other boundary layer parameters are re-evaluated.

When the wind speed is greater than $6 w_*$ convective scaling is no longer appropriate for modelling (due to the increased importance of vertical wind shear). In these windy cases the boundary layer is assumed to be a neutral boundary layer. If the wind speed is less than the greater of $1.2 w_*$ or 1.5 ms^{-1} the assumption that the concentration is independent of time (steady state assumption) is no longer valid. Modelling the concentration for these calm periods is not within the scope of currently available analytical dispersion models. Hence, the the wind speed during these calm periods is assign a speed of the greater of $1.2 w_*$ or 1.5 ms^{-1} and the other boundary layer parameters are evaluated using this wind speed.

2.2.2 Neutral Conditions

The boundary layer is assumed to be a neutral boundary layer when there is negligible surface heat flux ($H_0 \approx 0 \text{ Wm}^{-2}$) or when there are high wind speeds. For modelling purposes it is proposed that the heat flux be assumed to be negligible if its value does not exceed 5 Wm^{-2} and is not less than -5 Wm^{-2} . The only boundary layer parameters required for the neutral case are the friction velocity,

$$u_* = \kappa u / \ln(z_a / z_0), \quad (2.2.7)$$

and the boundary layer height, H , defined using the Tennekes (1973) neutral model,

$$H = 0.3 u_* / f_c \quad (2.2.8)$$

where f_c is the Coriolis parameter. (It is assumed in the models that $f_c = 10^{-4} \text{ s}^{-1}$).

If the wind speed is less than 1.5 ms^{-1} the steady state assumption implicit in the dispersion models may no longer be valid. For modelling purposes, during these periods the wind speed is assigned the value of 1.5 ms^{-1} and the boundary layer parameters are calculated based on this value.

2.2.3 Stable Conditions

The boundary layer is assumed to be stable if the surface heat flux is less than -5 Wm^{-2} . Under these conditions the boundary layer parameters required are: the Monin–Obukhov length scale, L , and the friction velocity,

$$u_* = \kappa u / (\ln(z_a / z_0) + 4.7 (z_a / L)). \quad (2.2.9)$$

When the Monin–Obukhov length scale, L , is plotted as a function of u_* based on measurements in a stable boundary layer it is observed (Venkatram, 1980b) that there is an empirical relationship between L and u_* . Venkatram (1980b) parameterized the Monin–Obukhov length as

$$L = 1100 u_*^2. \quad (2.2.10)$$

When the wind speed and hence u_* is small Venkatram's empirical fit is no longer valid (i.e., there are no real solutions to Eqs.(2.2.9) and (2.2.10)). If the wind speed which is less than the minimum necessary for real solutions it is assumed that L is equal to the value

given by the minimum wind speed which yields a real solution to Eqs.(2.2.9) and (2.2.10). This assumption is required in part because $z_a = L$. The value of u_* is then calculated according to Eq.(2.2.9) using the value of L and the observed wind speed.

Wind speeds less than 1.5 ms^{-1} are assumed to be calm. For modelling purposes, the wind speed during these calm periods is assigned the minimum value of 1.5 ms^{-1} .

When the Monin–Obukhov length scale exceeds 500 metres for modelling purposes the boundary layer is assumed to be a neutral boundary layer. Then the boundary layer parameters are calculated in the manner outlined in Subsection 2.2.2.

The stable boundary layer height, H , may be calculated using the stable boundary layer parameters, u_* and L , and Nieuwstadt's (1981) formulation.

$$H = 0.3 u_* (1 + 1.9 H/L) / f_c . \quad (2.2.11)$$

This equation reduces to the model of Brost and Wyngaard (1978) for L approaching zero and to the Tennekes (1973) neutral model (Eq.(2.2.8)) for very large L .

CHAPTER 3

DETERMINATION OF THE EFFECTIVE PLUME HEIGHT

As noted earlier the relative release height of material emitted into the planetary boundary layer will influence how the emissions will disperse. When material is released it may rise above its physical release height due to its inherent buoyancy or momentum. Also it may be subject to aerodynamic downwash. If released into the region of a structure wake the material may mix into the turbulent wake cavity. Complex terrain has the potential to affect the plume height for material dispersing in such settings. Hence, to proceed with the calculation of concentration it is first necessary to determine the effective release height for the sources being considered.

3.1 The Influence of Source Situation On the Release

3.1.1 Releases into a Structure Wake

Based on the source information and site data for the source complex being considered it is possible to determine which sources are located on or near a structure and, hence, will perhaps have their emissions mixed into the structure wake. A source may be considered to be close to a structure if it is located a distance of less than the greater of 2 times the structure height ($2 H_B$) or once the cross-wind width of the structure ($1 W_B$) measured from the closest face of the structure. This defines a nearby building. In general, stacks (including cooling towers) are not considered as structures for the purpose defining the structure upon which the source is located. However, large, free standing stacks may be considered nearby structures when viewed by small, adjacent sources.

For a given wind direction, it is assumed that material emitted at a physical height of less than twice the structure height ($2 H_B$) and less than ten times the structure width ($10 W_B$) is released into the highly turbulent wake region and is well mixed prior to dispersing downwind provided that the source is either within the greater of $2 H_B$ or $1 W_B$ of the structure. If the emissions are released at a height, z_s , which is less than $2 H_B$ but greater than $10 W_B$ then the release is assumed to be outside the well mixed wake region for this tall but relatively narrow structure. However the emissions are assumed to be subject to

structure induced downwash. If the emissions are released at or above the height $2 H_B$ (irrespective of z_s with respect to $10 W_B$) then the emissions are assumed to be outside the wake region. Appendix A discusses in detail how to determine if a source is near a building or group of structures and describes the modelling approach used for releases into a building wake region.

For each source, data on the dimensions of the nearby structures are input into the model. The width of the buildings would be calculated as described in Appendix A for wind directions grouped into 10° intervals.

If a source emits material on or near a structure and the physical release height, z_s , is less than $2 H_B$ and $10 W_B$ (where H_B is the greater height and W_B is the greater cross-wind width of the all nearby structures or the structure the source is on) then for modelling purposes it is assumed that mixing of the emitted material within the wake region will result in an effective ground level release, i.e.,

$$z_e = 0 \quad (3.1.1)$$

with an initial wake induced spread of the emissions proportional to the dimensions of the wake region. In turn, the dimensions of the wake are assumed proportional to the structure dimensions. Thus, the wake induced vertical spread is given by the initial mean plume height,

$$\bar{z}_o = 0.5 H_B \quad (3.1.2)$$

and the wake induced cross-wind spread is given by the initial horizontal dispersion parameter

$$\sigma_{yB} = 0.25 W_B. \quad (3.1.3)$$

The maximum value of W_B used in Eq.(3.1.3) is limited to be $4H_B$.

The effective release coordinates (x,y) for this emission are assumed to be coincident with the location of the building centre.

Inherent in this approach to modelling releases into a wake region is the assumption that irrespective of the initial buoyancy or momentum of the efflux it cannot rise out of the

wake region. In terms of the calculation of downwind ground level concentration this may be a conservative assumption, however, at present no models of plume rise within a wake region meet the selection criteria outlined in Part 1 of this Document for models suitable for inclusions into the dispersion modelling package.

Appendix A discusses the calculation of concentration at receptors on or with 5 metres of the building on or nearby which the source is located if the release height is less than $2H_B$.

3.1.2 Releases in Complex Terrain

A site is considered to be located in complex terrain if the release height is less than two times the maximum terrain height and if the gradient of the terrain is sufficiently large. Appendix D discusses recommended criteria for defining complex terrain. The degree to which contaminant dispersion is affected depends upon the meteorological conditions, the shape of the topography and the source location with respect to the terrain features.

Complex terrain situations have the potential to affect the plume height. To provide a conservative estimate for elevated sources in complex terrain, within the modelling package, the plume height is reduced to one-half the value of the effective release height calculated in the absence of complex terrain.

3.1.3 Area Sources

Area sources which do not emit into a wake region are treated in the modelling package as either point sources with initial cross-wind spread or as non-buoyant volume sources with initial vertical and cross-wind spread.

If an area source is treated as an effective point source modelling may proceed as it would for a point source located at the centre of the area but with initial cross-wind spread expressed in terms of a dispersion parameter

$$\sigma_{y_A} = 0.25 Y_A, \quad (3.1.4)$$

where, Y_A is the cross-wind extent of the source. Area sources treated as point sources may have release heights which are above grade level but usually these sources are emitting into a structure wake and should be treated appropriately.

If a non-buoyant area source is treated as a volume source it is assumed to be located at the centre of the area and to have initial spreads in the vertical and cross-wind directions defined, respectively, by the initial mean plume height,

$$\bar{z}_0 = 0.5 H_A, \quad (3.1.5)$$

where H_A is the height of the volume source, and by σ_{yA} . Area sources which are treated as volume sources are assumed to be located at grade level, hence, the effective release height, z_e , is zero.

An area source which emits into a structure wake (based on the location of the centre of the area source with respect to the structures) it is treated for modelling purposes in the manner outlined in Subsection 3.1.1.

3.1.4 Downwash of Emissions Released Outside a Wake Region

Emissions released from a stack or structure but not into a wake region may be subject during periods of relatively high wind speed to aerodynamic downwash induced by the stack or structure. Briggs (1973) suggests that the plume downwash below a stack of radius r_s may be estimated by

$$h_d = 4(w_s / u - 1.5) r_s \quad (3.1.6)$$

when the efflux vertical velocity, w_s , is less than $1.5u$.

If the release is located on or near a tall but relatively narrow structure such that the release height, z_s , is less than $2 H_B$ but is equal or greater than $10 W_B$ then the downwash is estimated by

$$h_d = 4(w_s / u - 1.5) W_B / 2. \quad (3.1.7)$$

Downwash reduces the effective release height of the plume but is assumed to not reduce the efflux buoyancy or momentum.

3.2 Plume Rise

Due to the inherent buoyancy and/or momentum of the efflux the plume may rise if it is not emitted into a structure wake. Momentum and buoyancy act together to drive the total rise,

however, in general if the release is buoyant it is the buoyancy which principally drives the rise. Hence, for modelling purposes plume rise due to source momentum flux and due to the source buoyancy are calculated independently. Then the total rise is based on the maximum of either the momentum or buoyancy induced rise.

Plume rise is not included for releases into a structure wake.

3.2.1 Evaluation of the Momentum and Buoyancy Flux

Prior to estimating plume rise it is necessary for modelling purposes to evaluate the buoyancy flux and vertical momentum flux for the source. For vertical releases of effluent which is less dense than ambient air due principally to its temperature, the source momentum flux is given by

$$F_m = T_{as} (w_s r_s)^2 / T_s \quad (3.2.1)$$

and the buoyancy flux is given by

$$F = g \left[\frac{T_s - T_{as}}{T_s} \right] w_s r_s^2 \quad (3.2.2)$$

where: r_s is the stack interior radius in meters measured at, z_s , the stack height in meters above grade; T_s is the efflux temperature ($^{\circ}\text{K}$); w_s is the efflux vertical exit velocity (ms^{-1}); and, T_{as} is the ambient temperature ($^{\circ}\text{K}$) at the release height z_s .

The ambient temperature, T_{as} , at the source release height is calculated by extrapolating the screen level ambient temperature measurement, T_a , upward to the release height. During convective and neutral periods it is assumed that the vertical temperature profile follows the dry adiabatic lapse rate and decreases at a rate of 0.0098°C/m . Hence, during convective and neutral periods

$$T_{as} = T_a - 0.0098(z_s - 2) \text{ if } z_s > 2 \text{ metres,} \quad (3.2.3a)$$

$$\text{and} \quad T_{as} = T_a \text{ otherwise.} \quad (3.2.3b)$$

During stable periods the ambient temperature at the source release height is calculated based on the atmospheric stability parameter S , the Brunt-Vaisalla frequency squared. S is approximated by

$$S = u_*^2 (0.74 + 4.7 z_m / L) / (\kappa^2 L z_m) \quad (3.2.4)$$

where the height z_m is equal to the source height unless z_s exceeds $2L$. In these cases, $z_m = 2L$ would be used when estimating S . This formulation for S is derived from substituting the stable temperature gradient surface similarity profile

$$\frac{\partial \theta}{\partial z} = \frac{\theta_*}{\kappa z} (0.74 + 4.7 z / L)$$

and the definitions

$$\theta_* = -\overline{\theta w}_0 / u_*$$

and

$$L = -\theta u_*^3 / (\kappa g \overline{\theta w}_0)$$

into the equation

$$S = \frac{g}{\theta} \frac{\partial \theta}{\partial z}.$$

If the meteorological measurements permit that S be derived from tower data, this data may be used in the modelling.

Once S is defined the ambient temperature at the source release height during stable periods is determined by

$$T_{as} = T_a + (z_s - 2) \Delta T / \Delta z, \text{ if } z_s > 2 \text{ metres,} \quad (3.2.5a)$$

and

$$T_{as} = T_a \text{ otherwise,} \quad (3.2.5b)$$

where

$$\Delta T / \Delta z = (T_a S / g) - 0.0098. \quad (3.2.6)$$

3.2.1.1 Special Considerations for the Determination of Source Fluxes

The above flux calculations assume that the mean molecular weight of the plume is not significantly different from the mean molecular weight of air. If this is not the case then the effect of the different molecular weights should be included in the calculation of the fluxes (see Briggs, 1975). To facilitate this option in the modelling package the fluxes for a source may be directly input rather than calculated as above. Note that the modelling package cannot be used for negatively buoyant emissions.

In addition if the source efflux is not principally vertically oriented it may be more appropriate to calculate the buoyancy and vertical momentum fluxes and directly input them.

If the emission source is a flare the buoyancy flux is enhanced by heat released during the burn. Appendix B provides directions for estimating the buoyancy flux and flame length for flares.

3.2.2 Momentum Induced Plume Rise

The rise due to the plume momentum may be approximated following Briggs (1975) as

$$\Delta h_m = 1.5 [F_m / (u u_*)]^{1/2}. \quad (3.2.7)$$

Plume momentum dissipates rapidly following release; hence, it is assumed in the modelling package that momentum induced rise occurs essentially instantaneously.

3.2.3 Buoyancy Induced Plume Rise

3.2.3.1 Convective Conditions

During convective periods a plume emitted into the boundary layer will dilute rapidly and loop up and down as it is caught in the convective updrafts and downdrafts. This downwind looping of the plume can result in the highest ground level concentrations. Venkatram (1980a) has expanded upon Briggs' (1975) plume "touchdown equation" to model the influence of convective downdrafts on a buoyant plume. This formulation circumvents the need to calculate plume rise for elevated releases in a convective boundary layer. However, to determine whether a plume is classified as an elevated or near surface release, plume rise for emissions into the convective boundary layer are estimated using the formula of Briggs (1984) for rise in strong convection

$$\Delta h_b = 3 z_i F^{*3/5}, \quad (3.2.8)$$

where
$$F^* = F / (w_*^2 u z_i) \quad (3.2.9)$$

is the nondimensional plume buoyancy.

3.2.3.2 Neutral Conditions

Theoretically, under neutral conditions the ambient vertical temperature gradient does not inhibit the rise of a buoyant plume. Briggs (1975) proposed that the maximum final or

terminal buoyant rise in a neutral boundary as limited by mechanically generated turbulence may be approximated as

$$\Delta h_{b_t} = \frac{1.3 F(1 + z_s/\Delta h)^{2/3}}{u u_*^2} . \quad (3.2.10)$$

However, Briggs noted that observations of plume rise in neutral conditions follow the "2/3 law" for rise of buoyant plumes as a function of downwind distance x , i.e.,

$$\Delta h_b(x) = \frac{1.6F^{1/3}}{u} x^{2/3} \quad (3.2.11)$$

and that terminal rise was not reported for many of the cases. Within the modelling package the minimum value of buoyant plume rise calculated using Eqs.(3.2.10) and (3.2.11) is used to define Δh_b in for a release into the neutral boundary layer. If available, the wind speed used in Eqs.(3.2.10) and (3.2.11) should be the value measured near the source release height.

3.2.3.3 Stable Conditions

Final plume rise in the stable boundary layer has been shown by Briggs (1975) to be given by

$$\Delta h_{b_t} = 2.6 (F/u S)^{1/3} \quad (3.2.12)$$

where S is the Brunt–Vaisalla frequency squared defined above. The wind speed used in Eq.(3.2.12) should be a near stack level value if this data is available in the meteorological input.

During periods of relatively weak stability and strong winds (large L), the plume rise formulations for neutral conditions described in the previous subsection are used to estimate the buoyant rise. Correspondingly, buoyant plume rise, Δh_b , during stable periods is assumed to be the minimum of Eq.(3.2.10), Eq.(3.2.12) or the minimum neutral value for the given downwind location x (Eq.(3.2.11)).

3.2.4 Moist Plume Rise

It has been suggested that cooling tower emissions and saturated plumes may have enhanced rise due to their large moisture content. For example, latent heat released during the ascent of a plume in an atmosphere near saturation would increase the plume buoyancy. The inclusion of moisture effects in the calculation of plume rise has been discussed by Briggs (1975). Briggs estimated that moisture could enhance rise by about 20% at maximum. At some point

downwind the liquid water would evaporate resulting in a decrease in plume buoyancy which would then limit the final plume rise. However, to include moisture effects when modelling plume rise requires several assumptions about the plume and ambient conditions. Hence, in view of the relatively small maximum change in the rise of a plume near saturation relative to the rise of a dry plume, moisture effects on plume rise have not been included in the modelling package.

The fall-out or rain-out of liquid water from a wet plume is not within the scope of currently available analytical models of plume rise and should be considered as a special circumstance.

3.3 Calculation of the Effective Plume Height

The effective plume height for material not emitted into a structure wake is defined as

$$z_e = z_s + h_d + \Delta h, \quad (3.3.1)$$

where Δh is the maximum of the momentum rise, Δh_m , or the buoyant plume rise, Δh_b . For flares the vertical flame length is also added to the source height.

During neutral and stable conditions if the plume rise is driven by buoyancy, plume rise is be a function of downwind distance increasing until the terminal rise, Δh_{b_t} , is reached. Hence, for distances less than

$$x_r = (\Delta h_{b_t} u / (1.6 F^{1/3}))^{3/2} \quad (3.3.2)$$

the effective release height is a function of downwind distance. Also the fraction of the plume which penetrates above the top of the boundary layer (see Subsection 3.4) may change for downwind distances less than x_r from the source.

In the stable or neutral boundary layers the initial dispersion of the plume due to its own turbulence may be significant relative to the ambient turbulence, hence, the plume is assigned an initial spread proportional to its plume rise. This initial spread is described in the modelling package by the dispersion parameters

$$\sigma_{y_p} = \Delta h/4 \quad (3.3.4)$$

and

$$\sigma_{z_p} = \Delta h/4. \quad (3.3.5).$$

3.3.1 Effective Plume Height for Releases in Complex Terrain

When a plume is released in a region of complex terrain the influence of the terrain on the flow and, hence, on the dispersion of the plume material is modelled by reducing the effective plume height by one half, i.e.,

$$z_{ec} = z_e / 2 \quad (3.3.6)$$

During convective conditions the source release height for elevated releases is reduced by one half; thus,

$$z_{sc} = z_s / 2. \quad (3.3.7)$$

Several models have employed the "half-height" approximation for modelling releases in the presence of complex terrain. For example see Egan (1975).

3.4 Plume Penetration Above the Boundary Layer

If the source is an elevated release based on the final effective plume height there is the potential for some of the emitted material to rise above the top of the planetary boundary layer. If material penetrates above the boundary layer it is assumed that this fraction of the plume does not contribute to the contaminant concentrations in the boundary layer.

The exception could occur during convective periods. If the source complex has been identified as being located near a major body of water and the flow is on shore emissions from tall stacks may be released into the stable air above a relatively shallow convective boundary layer. Away from the lake the convective boundary layer increases in depth until it reaches its inland value. As the plume located in the stable layer is advected away from the lake it may intersect with the growing convective boundary layer and then be subject to rapid downward mixing. This situation is referred to as a shoreline fumigation. For modelling purposes it is assumed that sources with release heights greater than the near shore convective boundary layer height can result in downwind fumigation. The modelling technique used for these sources is described in Appendix C. Near shoreline sources with release heights less than the boundary layer height are treated using the modelling techniques discussed in this Chapter and

Chapter 4; however, it is assumed that no plume penetration occurs for releases into the thermal internal boundary layer. Also, the meteorological data set used must reflect the local shoreline environment. Part 3 of the Air Quality Modelling Document discusses the localization of meteorological data sets.

3.4.1 Convective Conditions

Within the convective boundary layer there is vertical mixing driven by updrafts and downdrafts extending through nearly the whole boundary layer. The convective boundary layer is capped by stable air. In general, material released within the convective boundary layer will be rapidly mixed as the plume is essentially ripped apart as it is alternately caught in the updrafts and downdrafts. Currently, there are no analytical models available for plume penetration above the convective boundary layer which include the effects of the convective mixing on inhibiting the plume rise. In the absence of a more appropriate model for convective conditions, within the Ministry's dispersion modelling package it is assumed for the purpose of estimating plume penetration above z_1 that the plume is released into an essentially adiabatic boundary layer ($\partial\theta/\partial z \approx 0$) and rise is inhibited only by the stable stratification of the layer above. For buoyant material released near the top of an adiabatic boundary layer Manins (1979) estimates the amount of material which will remain in the boundary layer as

$$f = 1 \quad \text{if } P < 0.08, \quad (3.4.1a)$$

$$f = 0 \quad \text{if } P > 0.33, \quad (3.4.1b)$$

$$\text{or} \quad f = 0.08 P^{-1} - P + 0.08 \quad \text{otherwise,} \quad (3.4.1c)$$

$$\text{where} \quad P = F / (u b_1 [z_1 - z_s]^2) \quad (3.4.2)$$

$$\text{and} \quad b_1 = (g / \theta_a) \Delta\theta \quad (3.4.3)$$

$$\text{with} \quad \Delta\theta = 10^\circ\text{C}$$

based on climatological statistics (Holtzworth and Fisher, 1979).

It is assumed for modelling purposes that $\theta_a = T_a$.

3.4.2 Neutral Conditions

To test if an elevated release penetrates above the top of the neutral boundary layer, H , it is assumed that the plume is evenly distributed in the vertical and that the plume width is one times the plume rise at the current downwind location (following Briggs' (1975) suggestion). Then the fraction of plume material remaining in the boundary layer is

$$f = 1 \quad \text{if } \Delta h \leq (H - (z_s + h_d))/1.5, \quad (3.4.4a)$$

$$f = 0 \quad \text{if } \Delta h \geq 2(H - (z_s + h_d)), \quad (3.4.4b)$$

or
$$f = (1 - P) \quad \text{otherwise,} \quad (3.4.4c)$$

where
$$P = (1.5 - (H - (z_s + h_d))/\Delta h). \quad (3.4.5)$$

If only part of the plume remains in the boundary layer the effective plume height is defined as

$$z_e = 0.5 (H + (z_s + h_d)) + 0.25 \Delta h \quad (3.4.6)$$

3.4.3 Stable Conditions

To test if the plume, at least in part, rises above the top of the stable boundary layer, H , it is assumed (as in the neutral case) that the plume has a step-wise distribution in the vertical with a half width of $\Delta h/2$. Then the fraction of the plume which remains below H during stable periods is calculated in the same manner as for releases during neutral conditions and the effective release height, z_e , is re-evaluated in cases of partial penetration.

CHAPTER 4

CALCULATION OF DOWNWIND CONCENTRATION

This Chapter describes the methods used in the dispersion modelling package to calculate concentration downwind from sources emitting into the planetary boundary layer. These models may be applied to single sources or groups of sources. Calculated concentrations at downwind receptors due to the individual sources may be added together taking into account the relative source locations to determine the total concentration due to all sources in the area. Hence, in the following formulae x refers to the relative downwind distance between the specific source and the receptor ($x_{\text{receptor}} - x_{\text{source}}$) and y refers to the relative cross-wind location of the receptor with respect to the source ($y_{\text{receptor}} - y_{\text{source}}$).

4.1 Convective Meteorological Conditions

Concentration downwind of sources emitting into a convective boundary layer may be calculated using Nieuwstadt's (1980) convective scaling model when the effective source height above grade is less than the absolute value of the Monin-Obukhov length scale, L . Otherwise, Venkatram's (1980a) convective scaling, touch-down model is used to calculate the surface concentration downwind of the source.

4.1.1 Near Surface Releases

Nieuwstadt (1980) demonstrated that the cross-wind integrated, ground level concentration,

$$\bar{C}_0^y = \int_{-\infty}^{\infty} C(x, y, z=0) dy,$$

can be expressed as a function of the non-dimensional downwind, distance,

$$X = x w_* / u z_i, \quad (4.1.1)$$

such that

$$\bar{C}_0^y = 0.73 Q / u \bar{z} \quad (4.1.2)$$

$$\text{where} \quad \bar{z}/z_i = 0.812 X^{3/2} \quad \text{provided } \bar{z} < 0.73 z_i \quad (4.1.3a)$$

$$\text{otherwise} \quad \bar{z} = 0.73 z_i. \quad (4.1.3b)$$

\bar{z} defines the mean height to which the emission disperses downwind, and Q is the emission rate.

The cross wind dispersion of the plume is parameterized in terms of a Gaussian distribution. The lateral dispersion parameter σ_{y_a} due to the ambient atmospheric conditions is formulated as

$$\sigma_{y_a} = 0.6 z_i X/(1 + 0.7 X)^{1/2} \quad (4.1.4)$$

following the recommendations of Deardorff and Willis (1976) and Weil (1983). Then the lateral dispersion parameter σ_y is calculated using the assumption that the initial plume spread σ_{y_o} (due either to initial wake induced spread (σ_{y_B}) or due to initial spread determined by the dimension of an area source (σ_{y_A})), if applicable, and the ambient turbulence induced spreading σ_{y_a} are independent. Hence,

$$\sigma_y = (\sigma_{y_o}^2 + \sigma_{y_a}^2)^{1/2} \quad (4.1.5)$$

Thus

$$C(x,y,z=0) = \frac{C_o^y}{(2\pi)^{1/2} \sigma_y} \exp(-y^2/2\sigma_y^2). \quad (4.1.6)$$

The concentration for heights above ground level ($z = 0$) may be estimated using Horst's (1979) vertical exponential profile. Thus

$$C(x,y,z) = C(x,y,z=0) \exp(-(z/1.52 \bar{z})^{1.5}). \quad (4.1.7)$$

The above discussion assumes that the emission release height is zero, i.e., $z_e = 0$. Data from the Prairie Grass Experiment presented in Nieuwstadt (1980) indicates that Eq.(4.1.2) overestimates the surface concentration for receptors where $X < 0.033$. The Prairie Grass Experiment emissions were released near the surface but the non-zero source height becomes important for small X . Non-zero release heights may be included in the above

calculation by estimating a virtual, upwind ground level source location, x_0 , such that $\bar{z} = z_e$ when \bar{z} is calculated at $x = x_0$. Then the evolution of \bar{z} downwind from the source is calculated by evaluating Eq.(4.1.3) at $(x + x_0)$. The evaluation of σ_y is unchanged.

When $z_e = 0$ but there is initial vertical dispersion, \bar{z}_0 , as a result of wake induced spread or as a method for defining an initial volume for an area source, the upwind source location, x_0 , is calculated such that $\bar{z} = \bar{z}_0$ when \bar{z} is evaluated at $x = x_0$. Then the concentration downwind is calculated using \bar{z} evaluated at $(x + x_0)$. σ_y is calculated at x .

In some cases a near surface release with $z_e > 0$ may be considered as an elevated source when viewed at receptor locations very near to the source. For modelling purposes a source is considered elevated by all receptor located at downwind distances (x) which are less than x_0 . The modelling of concentration at receptors for which the source appears as an elevated release proceeds in the manner described in the Subsection 4.1.2. The exception is the unusual source for which both the source release height and the buoyancy flux are zero (i.e., $z_s = 0$ and $F = 0$). These sources are treated as near surface releases for all downwind locations.

4.1.2 Elevated Releases

The average ground level concentration due to emissions released into the mixed layer of the convective boundary layer may be calculated by solving

$$F^{1/3} x_i^{2/3} - w_d x_i = -z_s u \quad (4.1.8)$$

for x_i assuming that w_d , the mean downdraft velocity, is defined as $w_d = 0.5 w_*$. The most probable touchdown distance, x_i , is used to determine the downwind concentration distribution

$$C^y_{(x,z=0)} = \frac{f Q (1 + \operatorname{erf}(p/\sqrt{2}))}{2\sigma_z u} \quad (4.1.9)$$

where

$$p = \ln(x/x_i)/\ln(x_i/x'_i) \quad (4.1.10)$$

and x'_i is the value of x_i calculated assuming $w_d = 0.75 w_*$. f is the fraction of the plume remaining in the boundary layer. Q is the emission rate. A crosswind Gaussian distribution is assumed, hence,

$$C(x,y,z=0) = \frac{\overline{C}^y(x, z=0)}{(2\pi)^{1/2} \sigma_y} \exp(-y^2 / 2\sigma_y^2) \quad (4.1.11)$$

Venkatram (1980a) parameterized σ_y and σ_z in terms of the nondimensional downwind distance X (see Eq.(4.1.1)) and the nondimensional plume buoyancy, F^* , Eq.(3.2.9) such that

$$\sigma_y = 0.45 z_i (1.57 F^{*2/3} X^{4/3} + X^2)^{1/2} \text{ if } X \leq 1 \quad (4.1.12a)$$

$$\sigma_y = 0.45 z_i (1.57 F^{*2/3} X^{4/3} + X^{1.72})^{1/2} \text{ if } X > 1 \quad (4.1.12b)$$

and

$$\sigma_z = z_i (1 - \exp(-X - F^{*1/3} X^{2/3})). \quad (4.1.13)$$

4.2 Neutral Meteorological Conditions

The concentration downwind of sources emitting into a neutral boundary layer are calculated using van Ulden's (1979) surface similarity model for sources with releases at the surface ($z_e \leq z_o$). Emissions with source heights greater than ground level are treated using a Gaussian plume model.

4.2.1 Near Surface Releases

Van Ulden's (1979) model for dispersion near the surface is employed to calculate the concentration downwind from emissions with effective release heights, z_e , at the surface (i.e., $z_e \leq z_o$). The cross-wind integrated, ground level concentration can be approximated as

$$\overline{C}_0^y = 0.73 Q / \bar{u} \bar{z}, \quad (4.2.1)$$

where \bar{z} is the mean height to which the plume has dispersed and \bar{u} is the mean transport wind speed for the plume. The value of \bar{z} is determined by solving

$$x = 0.73 \bar{z} \ln(0.6 \bar{z} / z_o) / \kappa^2 \quad (4.2.2)$$

then the mean transport wind is given by

$$\bar{u} = u_* \ln(0.6 \bar{z} / z_o) / \kappa. \quad (4.2.3)$$

The maximum value of \bar{z} is limited to $\bar{z} = 0.73 H$ which occurs when the contaminant has mixed vertically through the boundary layer.

When the initial mean plume spread, \bar{z}_0 , is non-zero defining either the initial vertical spread by wake induced turbulence or the initial vertical extent of an area source, a virtual ground level source location is defined by solving Eq.(4.2.2) for x_0 assuming $\bar{z} = \bar{z}_0$. The mean transport wind speed \bar{u} is calculated using \bar{z} evaluated at $(x + x_0)$.

The lateral dispersion parameter σ_y may be evaluated using a formulation based on curves presented by Wyngaard et al. (1974) to describe the standard deviation of the cross-wind turbulent velocity fluctuations. Hence

$$\sigma_{y_a} = \frac{1.3 u_* x}{u (1 + (x/2500)^{1/2})} \text{ if } x < 10 \text{ kilometers,} \quad (4.2.4a)$$

and

$$\sigma_{y_a} = \frac{1.3 u_* x}{u (x^{1/2} / 33)} , \text{ otherwise.} \quad (4.2.4b)$$

Including the initial plume spread, σ_{y_0} , due either to wake induced spread or to define an area source, yields

$$\sigma_y = (\sigma_{y_0}^2 + \sigma_{y_a}^2)^{1/2}. \quad (4.2.5)$$

Then

$$C(x, y, z=0) = \frac{C_0^y}{(2\pi)^{1/2} \sigma_y} \exp(-y^2 / 2\sigma_y^2). \quad (4.2.6)$$

may be used to determine the ground level concentration and the concentration for heights above ground level may be estimated using Horst's (1979) vertical exponential profile such that

$$C(x, y, z) = C(x, y, z=0) \exp(-(z/1.52 \bar{z})^{1.5}). \quad (4.2.7)$$

4.2.2 Elevated Releases into a Neutral Boundary Layer

Concentration downwind from an elevated release into the neutral boundary layer is approximated using the Gaussian plume formulation. The formulation of the lateral and vertical dispersion parameters, σ_{y_a} and σ_{z_a} are estimated using Briggs' (1973) analytical equations

$$\sigma_{y_a} = 0.08 \times (1 + 0.0001 x)^{-1/2} \quad (4.2.8a)$$

and

$$\sigma_{z_a} = 0.06 \times (1 + 0.0015 x)^{-1/2} \quad (4.2.8b)$$

including the initial plume spreads due to the initial plume induced turbulence during plume rise yields

$$\sigma_y = (\sigma_{y_o}^2 + \sigma_{y_a}^2)^{1/2} \quad (4.2.9)$$

and

$$\sigma_z = (\sigma_{z_o}^2 + \sigma_{z_a}^2)^{1/2}. \quad (4.2.10)$$

The maximum value of σ_z is limited to $\sigma_z = H/(2\pi)^{1/2}$ corresponding to complete vertical mixing of the contaminant.

The downwind concentration due to an elevated release of gaseous emissions is determined by employing the effective plume height, z_e , and the above parameterizations of σ_y and σ_z in the Gaussian plume formulation:

$$C(x,y,z) = \frac{f Q}{2\pi \sigma_y \sigma_z u} \left\{ \exp\left[-\frac{(z - z_e)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z + z_e)^2}{2\sigma_z^2}\right] \right\} \exp\left[-\frac{y^2}{2\sigma_y^2}\right]. \quad (4.2.11)$$

4.3 Stable Meteorological Conditions

Downwind of sources emitting into a stable boundary layer the concentration is calculated using van Ulden's (1979) surface similarity model if the effective release height is very near

the surface. In the modelling package "near surface" is defined as z_e less than one-fiftieth the Monin-Obukhov length scale (i.e., $z_e \leq L/50$). Concentrations downwind from sources for which z_e is greater than $L/50$ are calculated using a revised Gaussian plume formulation.

4.3.1 Near Surface Releases

Using surface similarity scaling van Ulden (1979) showed that the cross-wind integrated, ground level concentration can be approximated as

$$\bar{C}_0^y = 0.73 Q / \bar{u} \bar{z}, \quad (4.3.1)$$

where \bar{z} is the mean height to which the plume has dispersed and \bar{u} is the mean transport wind speed for the plume. The value of \bar{z} is calculated by solving the following equation;

$$x = 0.74 \bar{z} (\ln(0.6 \bar{z} / z_0) + 4.9 \bar{z} / L) (1 + 4.9 \bar{z} / L) + 1.2 \bar{z} / L / \kappa^2 \quad (4.3.2)$$

and the maximum value of \bar{z} is given by the vertically well mixed limit $\bar{z} = 0.73 H$.

Then the mean transport wind speed is given by

$$\bar{u} = u_* (\ln(0.6 \bar{z} / z_0) + 4.7 \bar{z} / L) / \kappa. \quad (4.3.3)$$

The crosswind dispersion of the plume is parameterized in terms of a Gaussian distribution.

$$C(x, y, z=0) = \frac{\bar{C}_0^y \exp(-y^2 / 2\sigma_y^2)}{(2\pi)^{1/2} \sigma_y}. \quad (4.3.4)$$

The lateral dispersion parameter σ_y is calculated using the assumption that the initial plume spread σ_{y_0} (which may be due to plume induced spread, wake induce spread or to define the initial height of an area source) and the ambient turbulence induced spreading σ_{y_a} are independent. Hence,

$$\sigma_y = (\sigma_{y_0}^2 + \sigma_{y_a}^2)^{1/2} \quad (4.3.5)$$

where

$$\sigma_{y_a} = \frac{1.3 u_* x}{u} (1 - z_e / H) f_y(x). \quad (4.3.6)$$

The form of the universe function $f_y(x)$ is taken from Pasquill (1976) and Irwin (1979);

$$f_y(x) = (1 + (x/2500)^{1/2})^{-1}, \text{ if } x < 10 \text{ kilometers} \quad (4.3.7a)$$

$$f_y(x) = 33 x^{-1/2}, \text{ otherwise.} \quad (4.3.7b)$$

The vertical spread of the plume is assumed to follow an exponential form (Horst, 1979).

Thus
$$C(x,y,z) = C(x,y,z=0) \exp(-(z/1.52 \bar{z})^{1.5}). \quad (4.3.8)$$

If the effective release height, z_e , or the initial mean plume height, \bar{z}_0 , is non-zero then the above calculations are modified in the same manner as in the convective near surface release model. Given the effective source height or the initial mean plume height, Eq.(4.3.2) is solved for the virtual ground level source location, x_0 , assuming $\bar{z} = z_e$, or $\bar{z} = \bar{z}_0$, respectively. \bar{u} is calculated using Eq.(4.3.3) for the height $\bar{z}(x + x_0)$.

In some cases a near surface release with $z_e > 0$ may be considered as an elevated source when viewed at receptor locations very near to the source. For modelling purposes such a source is considered elevated by all receptor located at downwind distances (x) which are less than x_0 . The modelling of concentration at receptors for which the source appears as an elevated release proceeds in the manner described in the Subsection 4.3.2.

4.3.2. Elevated Releases into the Stable Boundary Layer

The downwind concentration due to an elevated release may be approximated using the Gaussian plume formulation. The lateral dispersion parameter, σ_y , may be calculated in the same manner as was employed in the stable, near surface release model (Eq.(4.3.5)). The ambient turbulence induced spread, σ_{y_a} , may be determined using Eqs.(4.3.6) and (4.3.7). The initial plume spread, σ_{y_0} , for the elevated release is given by Eq.(3.3.4) which describes the initial dispersion of the plume due to its own turbulence during plume rise. The vertical dispersion parameter, σ_z , may be estimated using the approximation of Wyngaard et al. (1975) for the standard deviation of the turbulent vertical velocity fluctuations

$$\sigma_w = 1.3 u_* (1 - z_e/H) \quad (4.3.8)$$

where

$$\sigma_{z_a} = \frac{\sigma_w x}{u} f_z(x). \quad (4.3.9)$$

The form of the universal function $f_z(x)$ was selected, based on Irwin's (1983) review of various σ parameterizations to be

$$f_z(x) = (1 + 0.9 (x/50u)^{1/2})^{-1}. \quad (4.3.10)$$

This parameterization was proposed by Draxier (1976) in his initial investigation of the form of $f_z(x)$.

Including the initial plume spread, σ_{z_0} , due to internal plume turbulence during plume rise gives

$$\sigma_z = (\sigma_{z_0}^2 + \sigma_{z_a}^2)^{1/2}. \quad (4.3.11)$$

σ_z is limited to a maximum value of $\sigma_z = H/(2\pi)^{1/2}$ corresponding to complete vertical mixing of the plume within the stable boundary layer.

The downwind concentrations due to an elevated release of gaseous emissions are determined by employing the effect plume height and the above parameterizations of σ_z and σ_y in the Gaussian plume formulation:

$$C(x,y,z) = \frac{f Q}{2\pi \sigma_y \sigma_z u} \left\{ \exp\left[-\frac{(z - z_e)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z + z_e)^2}{2\sigma_z^2}\right] \right\} \exp\left[-\frac{y^2}{2\sigma_y^2}\right]. \quad (4.3.12)$$

GLOSSARY OF SYMBOLS

Symbol	Units	Meaning
cc	—	cloud cover (sky cover in eights): octants
c_p	J/(Kg °K)	specific heat of dry air at constant pressure
C	g/m ³	concentration C(x,y,z) at location x,y,z with respect to the source (reported by the modelling package in micro-grams/cubic metre (µg/m ³))
C ^y	g/m ³	concentration integrated over y direction (i.e., $\int_0^{\infty} C(x,y,z)dy$)
d	—	Julian day (number 1 through 365 or 366)
DIR	—	surface wind speed direction measured at anemometer
f	—	fraction of plume mass remaining in the boundary layer
f_c	s ⁻¹	Coriolis parameter
F	m ⁴ s ⁻³	plume buoyancy flux
F _m	m ⁴ s ⁻²	source momentum flux
F*	—	non-dimensional plume buoyancy flux
g	ms ⁻²	acceleration due to gravity
h _d	m	plume downwash
H	m	stable or neutral boundary layer height
H _B	m	building or structure height
H _L	Wm ⁻²	long wave surface heat loss
H _O	Wm ⁻²	surface heat flux
L	m	Monin-Obukhov length scale
L _D	degrees	longitude of the meteorological station
L _R	radians	latitude of the meteorological station

P	—	factor measuring plume penetration above the boundary layer
Q	g/s	source emission rate (continuous for the averaging period)
r_s	m	inner radius at mouth of stack
R	Wm^{-2}	incoming solar radiation
sc	—	snow cover (yes or no flag)
S	s^{-2}	atmospheric stability parameter (Brunt–Vaisala frequency squared)
t	hr	time of day (GMT)
t_n	hr	local noon time (GMT for the meteorological station)
T	$^{\circ}K$	mean boundary layer temperature
T_a	$^{\circ}K$	surface temperature measure at approximately 2 metres
T_{as}	$^{\circ}K$	surface temperature extrapolated to the source height
T_s	$^{\circ}K$	source exit gas temperature
u	ms^{-1}	surface wind speed measured at anemometer level (10 metres)
u_e	ms^{-1}	optional elevated wind speed measured near source release height
\bar{u}	ms^{-1}	wind speed at mean plume height
u_*	ms^{-1}	friction velocity
w	ms^{-1}	vertical velocity
w_d	ms^{-1}	most probable downdraft velocity
w_s	ms^{-1}	source exit gas flow rate
w_*	ms^{-1}	convective scaling velocity
x	m	distance in the direction of the wind measured from the source
x_i	m	most probable downwind point of impingement of the plume

x_o	m	virtual source location for emissions from a near surface release (distance upwind from the source)
x_r	m	downwind distance at which terminal plume rise is reached
X	—	nondimensional distance downwind
X_i	—	most probable downwind point of impingement of the plume in nondimensional form
y	m	distance across wind
Y_A	m	cross-wind dimension of an area source
W_B	m	building or structure cross-wind width
z	m	vertical distance from grade at the source location
z_a	m	anemometer level (assumed 10 metres)
z_e	m	effective plume height (stack height minus downwash plus plume rise)
z_{ec}	m	effective plume height in complex terrain
z_i	m	convective boundary layer height
z_o	m	surface roughness length scale
z_s	m	stack height above grade
z_{sc}	m	reduced stack height for complex terrain
\bar{z}	m	mean plume height downwind from the source
\bar{z}_o	m	initial mean plume height
α		surface parameter relating incoming solar radiation to the surface heat flux ($\alpha \approx .35$), if snow covered $\alpha = 0$
β		cloud cover radiation reduction parameter
$\partial\theta/\partial z$	$^{\circ}\text{Km}^{-1}$	partial derivative of potential temperature with respect to height
Δh_b	m	plume rise due to buoyancy of the emission
Δh_{b_t}	m	terminal (final) buoyant plume rise
Δh_m	m	plume rise due to momentum
Δh	m	plume rise as minimum of either the buoyancy or momentum driven rise

$\Delta\theta_i$	$^{\circ}\text{K}$	temperature change over the depth of the temperature inversion capping the convective boundary layer
ϕ	radians	solar declination
π	—	mathematical constant $\pi = 3.14159\dots$
κ	—	von Karmen constant ($\kappa = 0.35$)
ρ	kg/m^3	density of air near the surface
θ	$^{\circ}\text{K}$	potential temperature (a function of temperature and pressure)
θ_*	$^{\circ}\text{K}$	scaling temperature
$\overline{\theta w}_0$	$^{\circ}\text{K m/s}$	surface kinematic turbulent heat flux
τ	radians	solar elevation
σ_w	ms^{-1}	standard deviation of vertical velocities
σ_y, σ_z	m	total cross-wind (horizontal) and vertical spread of the plume
$\sigma_{y_a}, \sigma_{z_a}$	m	cross-wind (horizontal) and vertical spread of the plume due to ambient turbulence
$\sigma_{y_p}, \sigma_{z_p}$	m	initial cross-wind and vertical spread of plume due to internal plume turbulence during plume rise
$\sigma_{y_o}, \sigma_{z_o}$	m	initial cross-wind and vertical spread of plume
σ_{y_A}	m	horizontal spread of plume use to describe the cross-wind dimension of an area source
σ_{y_B}	m	horizontal spread of plume due to wake induced turbulence

REFERENCES

- Briggs, G.A. 1973: "Diffusion estimates for small emissions", ATDL Contribution File No. 79, U.S. E.P.A. Atmospheric Turbulence and Diffusion Laboratory.
- Briggs, G.A., 1975: Plume rise predictions, in: Lectures on Air Pollution and Environmental Impact Analyses, Workshop Proceedings, A.M.S. Boston, MA. 59–111.
- Briggs, G.A., 1984: Plume rise and buoyancy effects, in "Atmospheric Science and Power Production", D. Randerson, Ed., U.S. Dept. of Energy, 327–366.
- Brost, R.A. and J.C. Wyngaard, 1978: A model study of the stably stratified planetary boundary layer. *J. of Atmos. Sci.*, 35, 1427–1440.
- Draxler, R.R., 1976: Determination of atmospheric diffusions parameters, *Atmos. Environ.* 10, 99–105.
- Deardorff and Willis, 1975: A parameterization of diffusion into the mixed layer, *J. Appl. Meteor.*, 14, 1451–1458.
- Egan, B.A., 1975: Turbulent Diffusion in Complex Terrain, in: Lectures on Air Pollution and Environmental Impact Analyses, Workshop Proceedings, A.M.S. Boston, MA. 112–135.
- Holzworth, G.C., 1967: Mixing depths, wind speeds and air pollution potential for selected locations in the United State, *J. Applied Met.*, 6, 1039–1044.
- Horst, T.W., 1979: Lagrangian similarity modelling of vertical diffusion from a ground level source, *J. Appl. Meteor.*, 18, 733–740.
- Irwin, J.S., 1979: "Estimating Plume Dispersion – A Recommended Generalized Scheme", in preprints of "Fourth Symposium on Turbulence, Diffusion, and Air Pollution", A.M.S., Boston MA., 62–69.

- Irwin, J.S., 1983: Estimating plume dispersion – a comparison of several sigma schemes, *J. of Clim. and Appl. Meteor.*, 22, 92–114.
- Lilly, D.K., 1968: Models of cloud–top mixed layers under a strong inversion, *Q.J. Meteor. Soc.*, 95, 292–309.
- Manins, P.C., 1979: Partial penetration of an elevated inversion layer by chimney plumes, *Atmos. Environ.*, 13, 733–741.
- Maul, P.R., 1980: "Atmospheric Transport of Sulphur Compound Pollutants" C.E.G.B. Report MID/SSD/80/0026/R, pp 194.
- Misra, P.K., 1980: Dispersion from tall stacks into a shoreline environment, *Atmos. Environ.*, 14, 393–397.
- Nieuwstadt, F.T.M., 1980: Application of mixed–layer similar to the observed dispersion from ground level sources, *J. Appl. Meteor.*, 19, 157–162.
- Nieuwstadt, F.T.M., 1981: The steady–state height and resistance laws of the nocturnal boundary layer: Theory compared with Cabauw observations, *Boundary Layer Meteor.*, 19, 3–17.
- Pasquill, F., 1974: "Atmospheric Diffusion", 2nd Edition, J. Wiley and Sons, New York, pp 429.
- Pasquill, F., 1976: "Atmospheric Dispersion Parameters in Gaussian Plume Modelling: Part II. Possible Requirements for Change in the Turner Workbook Values: Report EPA–600/4–760306, U.S. Environmental Protection Agency.
- Seinfeld, J.H., 1975: "Air Pollution", McGraw–Hill Inc., New York, pp 523.
- Tennekes, H., 1973: Similarity laws and scale relations in planetary boundary layers, in "Workshop on Micrometeorology". AMS, Boston, MA., pp 392.

Ulden, A.P. van, 1978: Simple estimates for vertical diffusion from sources near the ground, *Atmos. Environ.*, 12, 2125–2129.

Venkatram, A., 1978: Estimating the convective velocity scale for diffusion application, *Boundary Layer Meteor.*, 15, 447–452.

Venkatram, A., 1980a: Dispersion from an elevated source in a convective boundary layer, *Atmos. Environ.*, 14, 1–10.

Venkatram, A., 1980b: Estimating the Monin–Obukhov length in the stable boundary layer for dispersion calculation, *Boundary Layer Meteor.*, 19, 481–485.

Weil, J.C. 1983: "Application of advances in planetary boundary layer understanding to diffusion modelling" in "Proceedings of Sixth Symposium on Turbulence and Diffusion", AMS, Boston, MA, 42–46.

Willis, G.E. and J.W. Deardorff, 1983: On plume rise within the convective boundary layer, *Atmos. Environ.*, 17, 2435–2447.

Wyngaard, J.C., O.R. Cote, and K.S. Rao, 1974: Modelling the atmospheric boundary layer, *Adv. Geophys.*, 19A, 193–211.

APPENDIX A

MODELLING AIR QUALITY DUE TO CONTAMINANT RELEASES FROM A LOCATION ON OR NEAR A BUILDING

A.1 Introduction

The dispersion of pollutants released near buildings or other structures can be influenced by the turbulence induced by these structures in the flow around them. In these circumstances the calculations of pollutant concentration must take into account the effects of this building-induced turbulence.

In close proximity to the building there is a 'wake cavity' region which is highly turbulent, where recirculation occurs and mean wind speeds are reduced (Huber, 1984). In the downwind wake beyond the cavity, the turbulence intensity decreases progressively to the ambient atmospheric level.

Accurate estimates of concentrations of pollutants from sources which are influenced by the presence of nearby buildings can be made only for very simple building structures. The definition of simple building structures is described in the following paragraphs. Most buildings do not conform to this definition of a simple building. In these cases engineering estimates of concentrations in the presence of buildings can nevertheless be made. This document describes the equations applicable for simple buildings and the criteria for their application to structures which are not so simple.

A.2 Definition of 'Simple Building or Structure'

The modelling approach described here is for estimating the air concentration of a contaminant downwind from a release point on or near a building or structure with horizontal and vertical dimensions which are comparable in size. This is based on a survey of the evaluation of several simple modelling methods for contaminant concentrations downwind of influencing structures (e.g., Huber, 1984; Fackrell, 1984; Ogawa et al, 1983). The majority of observational data are for simple rectangular or cylindrical structures.

Hence, the testing of the modelling concepts for dispersion as influenced by buildings or structures have only been assessed for such simple structures.

As a guideline regarding relative building dimensions, a simple structure is defined as one in which the maximum horizontal length of face of the building or structure (L_{\max}) is not greater than five times the minimum horizontal length of face of the structure (L_{\min}). The height (H_B) of the building or structure should be between 1/2 and 2 times the minimum horizontal length scale of the building. In addition, the building or structure should be approximately rectangular in shape without complicated roof lines or distortions in the overall shape of the building or structure.

For releases on or near buildings or structures which do not conform to these guidelines, simplifications of the building shape for the purpose of making the building wake calculations may be made. Some recommended procedures are given in the sections which follow. However, the concentrations of pollutants computed as a result of these simplifications may be subject to relatively large errors. In such cases physical modelling may be undertaken at the discretion of the proponent.

A.3 Clusters of Buildings

Buildings and other structures frequently exist in clusters. Within a cluster of buildings the flow pattern may be very complicated. In the far wake region (i.e., well beyond the downwind extent of the wake recirculation cavity) of a tightly clustered group of structures with similar heights, the clustered buildings or structures have been viewed as a single effective structure (e.g. Huber, 1984).

Some simplification can be made by assuming that if two buildings are situated sufficiently close to each other they may be considered as one contiguous building with regard to the building induced turbulence. The criterion applied here is that if the distance between the closest edges of two buildings is equal to or less than the height H_B of the tallest of the two buildings, they may be considered as a single structure of height H_B for the building wake calculation.

A.4 Conditions for Influence of Building–Induced Turbulence

Relationships between the release height of the contaminant, the heights of nearby buildings and their distances from the point of release, will determine whether dispersion is influenced by the turbulence surrounding the buildings. These effects are discussed in the following sections and criteria established that, for the purposes of modelling, will define the circumstances in which building–induced turbulence is to be taken into account in computing downwind concentrations.

A.4.1 Emission Height Relative to The Building/Structure Height

The dispersion of material released on or near a building or structure is assumed to be influenced by structure–induced turbulence if the release height less than two times the building height H_B . Otherwise, the release may be treated as if the building or structure is not present. If material is released at heights less than $2H_B$ it may be trapped within the building wake recirculation. This criterion is based on Wilson's (1979) parameterization of depth of the roof recirculation zone for simple structures. Material released in the recirculation cavity can be well–mixed within this region prior to dispersion downwind.

A.4.2 Emission Height Relative to Building Width

If the release height is less than two times the building height, but is equal to or greater than ten times the building width, the released contaminants will be considered to be outside of the building–induced turbulence and may be treated as if the building or structure is not present. Downwash in this case is calculated using the building width W_B in place of the stack diameter.

Contaminants released from cooling towers are considered to be outside of the turbulence induced by the towers and therefore are not subject to the requirements given above.

A.5 Definition of Building Height

The height of the building is defined as the maximum height of the building itself. If there is a structure such as a penthouse or storage tank on the top of a building, the building

height H_B may in some circumstances be taken as the height to the top of this structure, depending on the size and location of the structure relative to the building. This will be considered on a case by case basis.

A.6 Definition of 'Near'

The release of a contaminant in close proximity to a building will influence the dispersion of the material. For a source upwind of a building, Wilson and Netterville (1978) found that a simple structure's influence on the contaminant dispersion extended upwind a distance of approximately 1.3 times the building height. Material released at a distance of less than 1.3 H_B from the upwind edge of the building may be entirely trapped in the region of distorted flow and high turbulence which can form around the structure.

The region of building-induced turbulence wraps around the structure. Therefore, dispersion of material released near the sides of a building may be influenced by the flow distortions around the building. Studies by Penwarden and Wise (1975) (as reported by Hosker, 1984) indicated that the cross-wind extent of the flow distortion at the sides of a structure may extend a distance approximately equal to the building width (in the cross-wind direction) from the side of the structure. This distance may be less for buildings on which the flow re-attaches to the sides of the structure following distortion at the upwind face of the building.

On the downwind side of a structure or building there will be a wake cavity zone. Within this region the turbulent flow pattern is very complex. Huber (1977) recommended that his formulation for dispersion be applied to sources that are within a distance of 2 H_B downwind of a building. Briggs (1976) restricted his calculations for wake effects to sources directly downwind of a building within a distance equal to 3 times the smaller of: the building height or the width perpendicular to the wind direction.

For the modelling methods in this document an emission source will be considered to be sufficiently near a building or structure for the downwind concentration of contaminants to be influenced by building-induced turbulence if the source is located anywhere within a distance of two times the building height or once the building width (whichever is greater)

from the edge of the structure. The building width is defined as the maximum projection of width in any direction.

It will be assumed that material released at a height of less than $2 H_B$ within this distance is trapped in the high turbulence region and is well mixed within the building cavity prior to dispersing downwind.

A.7 The Concentration Calculation

A.7.1 Concentration in the Building Cavity Region

The hourly averaged concentration, C , of a contaminant released on or near a building, at receptors on the building, or within five metres horizontally of the building can be estimated using the expression:

$$C = 0.6 Q / L^2, \quad (\text{A.7.1})$$

where Q is the hourly averaged release rate of contaminant and L is the horizontal distance from the point of release to the receptor. The minimum value of L to be used is 5 m. The maximum value of L to be used is the minimum cross-sectional dimension of the building exposed to the wind.

If the calculated value of the concentration, C , exceeds the concentration at the point of release then the value of C is to be set equal to the concentration at the point of release.

Where the comparisons are to be made with air quality criteria of 24 hours or longer, $1/4$ of the hourly concentration C calculated in Eq.(A.7.1) should be used in the comparison.

Eq.(A.7.1) is the model employed in the Appendix to Regulation 308 (Section 2, Subsection A). It is equivalent to the expression proposed by Barry (1964) and Meroney (1982):

$$C = Q / (a_1 u A_p),$$

with $1/(a_1 u)$ replaced by 0.6 and A_p replaced by L^2 .

Since most buildings will not conform to the guidelines for simple buildings, the following procedure recommended for general application of Eq.(A.7.1). First, compute the

concentration according to Eq.(A.7.1) above. Then if the computed concentration is greater than or equal to 1/2 of the air quality standard for the pollutant, and the building or structure does not conform to the simple building definition, then physical modelling is recommended.

A.7.2 Concentration Beyond the Cavity Region

To calculate concentration of a contaminant released on or near a building at receptors downwind and beyond the region of high turbulence induced by the structure, it is recommended that the release be treated in the following manner.

First, assume that the effective release height is at ground level, i.e.,

$$z_e = 0 \quad (\text{A.7.2})$$

Second, assume that the initial vertical mixing of the material by building-induced turbulence has resulted in the contaminant being mixed to a mean height, \bar{z}_0 , equal to 1/2 the building height, i.e.,

$$\bar{z}_0 = H_B / 2. \quad (\text{A.7.3})$$

Then, for the appropriate boundary stability, apply the near surface release modelling described in Chapter 4 of this Part of the Document, with $\bar{z}_0 = 1/2 H_B$, used to calculate the virtual, upwind source location x_0 relative to the release point.

Third, assume that the building-induced turbulence will also enhance the initial cross-wind dispersion of material released on or near the building such that the initial cross-wind spread parameter is proportional to the width of the building exposed to the wind, W_B .

Defining $\sigma_{y_B} = 1/4 W_B$, (A.7.4)

subsequent the total lateral spread is then calculated using

$$\sigma_y = (\sigma_{y_a}^2 + \sigma_{y_B}^2)^{1/2}, \quad (\text{A.7.5})$$

where formulation of the ambient lateral dispersion parameter σ_{y_a} is a function of atmospheric stability as described in Chapter 4.

Finally, concentration at a downwind receptor is computed using the modelling method detailed in Chapter 4 for surface releases.

There is a maximum allowable value of W_B in Eq.(A.7.4). If the building width W_B exceeds four times the building height H_B then the value of W_B in Eq.(A.7.4) is replaced by $4 H_B$.

A.8 Downwind Distance from Assumed Release Point at Building Centre

For building-induced turbulence, downwind distance is defined by assuming that the point of release is at the centre of the building. For most buildings the shape will not be a simple rectangle. To determine the centre of the building for the modelling calculations a rectangle is drawn as an envelope of the building by first drawing two parallel lines which define the maximum projection of the building in the cross-wind direction. The rectangle is completed by drawing two parallel lines which define the maximum projection perpendicular to the first pair of lines. The intersection of the two diagonals of the rectangle define the centre of the building where the release point is assumed to be for the purpose modelling downwind concentrations.

A cluster of buildings can be treated in a similar manner, drawing the envelope around the whole cluster.

References

Barry, P.J., 1964: Estimation of downwind concentration of airborne effluents discharged in the neighbourhood of buildings. Atomic Energy of Canada Ltd., Report #2043, 16 pp.

Briggs, Gary A., 1976: Estimation of downwash effects; in "Power Generation", Noll and Davis, Ed., pp 65–70.

Fackrell, J.E., 1984: An examination of simple models for building influenced dispersion; Atmos. Environ., 18, pp 89–98.

Hosker, R.P., 1979: Empirical estimation of wake cavity size behind block-type structures. Fourth Symposium on Turbulence, Diffusion and Air Pollution, Reno, NV, January 15–18, American Meteor. Soc., Boston, MA, pp 603–609.

Hosker, B.P., 1984: Flow and diffusion near obstacles. Atmospheric Science and Power Production, D. Randerson Ed.; U.S. Dept. of Energy Tech. Info. Center, Oak Ridge, TN.

Huber, A.H., 1977: Incorporating building/terrain wake effects on stack effluents; Joint Conference on Applications of Air Pollution Meteorology, Salt Lake City, Utah, November 29–December 2; American Meteor. Soc., Boston, MA, pp 353–356.

Huber A.H., 1984: Evaluation of a method for estimating pollution concentrations downwind of influencing buildings. Atmos. Environ., 18, pp 2313–2338.

Meroney, R.M., 1982: Turbulent diffusion near buildings. Engineering Meteorology, E.J. Plate Ed.; Elsevier Scientific Pub. Co., Amsterdam.

Ogawa, V., S. Oikawa and K. Uehara, 1983: Field and wind tunnel study of flow and diffusion around a model cube –II Nearfield and cube surface flow and concentration patterns. Atmos. Environ., 17, pp 1161–1171.

Penwarden, A.D. and A.F.W. Wise, 1975: Wind Environment Around Building Research Establishment Report; Her Majesty's Stationery Office, London.

Wilson, D.J., 1979: Flow patterns over flat roofed buildings and application to exhaust stack design. ASHRAE Trans., 85, part 2, pp 284–295.

Wilson, D.J. and D.D.J. Netterville, 1978: Interaction of a roof-level plume with a downwind building; Atmos. Environ., 12, pp 1051–1059.

APPENDIX B

DETERMINATION OF FLARE BUOYANCY FLUX AND FLAME LENGTH

The buoyancy flux for a flare may be calculated as:

$$F = \frac{g}{\pi} \frac{Q_s}{\rho T_{as} c_p} ; \quad (B.1)$$

where g is the acceleration due to gravity (ms^{-2}), ρ is the near surface ambient density of air (Kg/m^3), T_{as} is the ambient air temperature at the source height ($^{\circ}\text{K}$), c_p is the specific heat of dry air at constant pressure ($\text{J}/(\text{Kg } ^{\circ}\text{K})$) and Q_s is the rate at which sensible heat is released from the flare (watts).

The sensible heating rate may be calculated as

$$Q_s = BHK_1K_2 , \quad (B.2)$$

where B is the rate at which fuel is burned, H is the heat of combustion of the gas, K_1 is the fractional efficiency of the combustion process, and K_2 represents the fraction of the heat of combustion which is released as sensible heat. The values of B and H may be readily determined given the specific operating conditions of the flare. Deriving appropriate values for K_1 and K_2 is more difficult. In the absence of measurements for the specific flare, the fractional efficiency of the combustion may be assumed to have a value of $K_1 = 0.9$. The fraction of the flare heat released as sensible heat, K_2 , was assign a value of $K_2 = 0.45$ by Leahey and Davies (1984) for sour gas flares. In the absence of data for the flare being assessed it is recommended that $K_2 = 0.45$ be used to calculate Q_s .

Once the flare buoyancy flux has been calculated the effective release height, z_e , of the combusted gas plume emitted by flare flame may be estimated as

$$z_e = z_s + h_f + \Delta h_b, \quad (B.3)$$

where z_s is flare stack height above grade, h_f is the vertical flame height, and Δh_b is the buoyant plume rise for the given atmospheric conditions. Based on the flare buoyancy flux, F , calculated using Eq.(B.1), the buoyant plume rise may be evaluated in the manner described in Subsection 3.2.3 of Chapter 3.

Flare flame length may be estimated using the simple correlation between the flare sensible heat release and flare length reported by Beychok (1979). Assuming that the flame tilt caused by the horizontal wind is 45° and converting the correlation to metric units, the vertical extent of the flame, h_f (m), may be approximated as

$$h_f = 0.0023 Q_s^{0.478}. \quad (\text{B.4})$$

References

Beychok, M.R., 1979: "Fundamentals of Stack Gas Dispersion", M.R. Beychok, Ed., Irwin, CA, USA.

Leahey, M. and N.J.E. Davies, 1984: Observations of plume rise from sour gas flares. Atmos. Environ., 18, 917–922.

APPENDIX C

MODELLING AIR QUALITY FOR RELEASES IN A LAKESHORE SETTING

The lakeshore marks an almost immediate change in surface roughness, temperature and evaporation to which the low-level air flow must react. Hence, these changes in surface conditions affect the transport and dispersion of contaminants released near the lakeshore.

C.1 Diffusion During On-Shore Flow

Modelling diffusion of a contaminant released near a lakeshore during on-shore flow is complicated by the transition of surface conditions from lake to land. On-shore flow of stable air (frequently stabilized by heat loss at the surface during advection over a relatively cold lake surface) to warm land surface heated by the sun creates conditions ideal for continuous fumigation of elevated contaminant releases. As the flow crosses the lake-land interface the surface changes result in the formation of internal boundary layers. The thermal internal boundary layer which forms as a result of surface heating over land gradually deepens inland from the shore. Plumes which are released into the stable air near the shoreline can eventually be transported inland and become entrained in the deepening unstable (thermal internal) boundary layer. The rapid mixing of the plume to ground following its intersection with the thermal internal boundary layer may persist for several hours, and, hence, is referred to as continuous fumigation. Section 5 of this Appendix outlines a model suitable for estimating contaminant air concentrations downwind from a near shoreline elevated release.

A second dispersion regime which may occur for releases near a shoreline during on-shore flow is plume trapping. Figure C.1 illustrates fumigation and plume trapping in the thermal internal boundary layer.

The thermal internal boundary layer which develops inland from the shoreline may be relatively shallow, compared to the depth of the boundary layer which would exist for the same conditions in the absence of lake effects. Hence, the vertical dispersion of plume released into this shallow boundary layer will be limited when compared to the vertical

dispersion which could occur in a deeper, inland boundary layer. It is recommended that when modelling releases into the thermal internal boundary layer, the boundary layer height at the source location be employed for calculation purposes rather than a boundary layer depth based on inland measurements. No plume penetration should be allowed in these cases since any material which does penetrate above the convective boundary layer near the source location would quickly be re-entrained back into the thermal internal boundary layer farther inland. Otherwise, these cases may be modelled as releases into the convective boundary layer as described in Chapters 3 and 4 in this Part of the Air Quality Modelling Document.

C.2 Other Shoreline Diffusion Regimes

There are two other situations where the lake-land temperature contrast could affect the dispersion of pollutants. When a lake is warmer than the neighbouring land surface, the flow of cold, stable air from the land to over the warmer water could result in fumigation offshore over the water. Alternatively, if an unstable air mass over a relatively warm lake is advected over a cold land surface then the convective eddies would decay with distance inland. In these cases dispersion close to the shore would be different than suggested by the stable conditions defined by the inland meteorological measurements.

These two dispersion regimes are not included in the modelling package since they occur less frequently than the cases where there is on-shore flow resulting in the formation of a thermal internal boundary layer and most critical receptors are located on the land.

C.3 Defining Near-Shore Sources

All sites located within 15 kilometres of a major body of water are considered to potentially near-shore sites. Within the source complex the sources must be considered individually based on the release height of the contaminant relative to the height of the thermal internal boundary layer. Observational studies have shown that the height of the boundary layer during on-shore flow may be approximated as

$$H = A (x + x_o)^{1/2}, \quad (C.3.1)$$

with

$$x_o = h_o^2 / A.$$

Where h_0 is the shoreline boundary layer height for these hours and has been defined as 50 metres for non-urban settings and 100 metres for urban settings, x is the distance downwind from the shore-line measured along the wind direction and A is a parameter dependent upon the transition in surface conditions at the lake/land interface. Typically the value of A ranges between 1.5 and 6; hence, the range of plausible thermal internal boundary layer heights at a given inland, source location, x , may be determined. Specific values of A may be estimated in the manner described in Part 3 of the Documentation which discusses localized meteorological effects. If the source release height including plume rise is greater than any possible value of H at the source location, the potential for fumigation of the plume must be included in the modelling assessment.

C.4 Medium Scale Influences of Large Lakes

In a coastal environment the existence of local circulations, commonly known as lake/land breezes, is well documented. These local circulations develop in response to differential heating and cooling at the land/water interface. During the daytime the land surface temperature rises rapidly due to incoming solar radiation, whereas the water temperature stays almost constant (due to its large heat capacity). The resulting pressure gradient sets up a circulation cell with on-shore winds at lower levels and return flow at upper levels. This process is reversed during the night time with land cooling rapidly to a lower temperature than that of the neighbouring water body. The development of lake/land breezes may modify the local flow pattern such that meteorological data collected at inland sites, or sites in other coastal environments, are non-representative. Hence, care must be exercised when developing a meteorological data set for modelling releases in a lakeshore setting. See Part 3 of the Air Quality Modelling Document for a discussion on the localization of meteorological data sets.

For cases when the source release height is less than the height H calculated in Eq.(C.3.1), it is still necessary to consider the influence of lake on the convective boundary layer height when compiling a meteorological data set.

C.5 A Shoreline Fumigation Model

On-shore flow during the daytime may bring a stable air mass over the water onto a rapidly heating land mass. As the air mass moves inland, it is heated from below and a convective boundary layer develops which is usually referred to as a thermal internal boundary layer. Plumes emitted from stacks located near the shoreline fumigate when they intersect this convective boundary layer. In this Section a fumigation model developed by Misra (1980) is described.

Misra (1980) assumed that the dispersion of pollutants within the stable layer and within the thermal internal boundary layer proceeds independently. This is because the turbulent characteristics of each layer are different from the other and they are separated by a fairly well defined surface (i.e. the top of the boundary layer). When the plume intersects the thermal internal boundary layer, dispersion into the boundary layer is assumed to occur from an area source located under the surface of the top of the boundary layer. The model assumes vertical and crosswind Gaussian distribution of the plume in the stable layer; and a uniform vertical distribution and Gaussian crosswind distribution of the plume in the internal boundary layer. Then the ground level concentrations are:

$$C(x,y,z=0) = \frac{Q}{2\pi H u_m} \int_0^x \frac{1}{\sigma} \exp \left[-\frac{(H-h)^2}{2\sigma_z^2} - \frac{y^2}{2\sigma_y^2} \right] \frac{d}{dx'} \left[\frac{(H-h)}{\sigma_z} \right] dx' \quad (C.5.1)$$

$$\text{where:} \quad \sigma^2 = (\sigma_y^2(x') + \sigma_y^2(x-x')) \quad (C.5.2)$$

is the net lateral spread; H is the internal boundary layer height; h is the plume height (stack height + plume rise); u_m is the mean wind speed in the boundary layer; σ_z and σ_y are the standard deviations of the plume in the vertical and crosswind directions; Q is the emission rate; x is the distance downwind from the shoreline measured in the along wind direction; and, x' is the distance downwind from the point on the boundary layer interface where the plume intersects the convective boundary layer.

Note that the subscripts 'c' and 's' refer to convective and stable regimes respectively. For further details on the model see Misra (1980).

Boundary layer height, H, may be calculated using Eq.(C.3.1) with the parameter .

A prescribed a priori from climatological data or calculated from

$$A = \frac{u_*}{u_m} \left[\frac{2(\theta_L - \theta_w)}{\Gamma} \right]^{1/2}, \quad (C.5.3)$$

where u_* is the friction velocity over land, θ_L and θ_w are the potential temperatures over land and water respectively, and Γ is the lapse rate ($\partial\theta_w/\partial z$) over water.

In the lakeshore environment, rise of a plume released into the stable layer may be modelled following Misra and Onlock (1982) which gives

$$h = z_s + 1.0 \frac{F^{1/3} x^{2/3}}{u_s}; \quad \frac{x}{u_s} \leq \tau \quad (C.5.4a)$$

$$\text{and} \quad h = 2.4(F/N^2 u_s^2)^{1/3}; \quad \frac{x}{u_s} > \tau \quad (C.5.4b)$$

where z_s is the stack height, F is the plume buoyancy flux, τ is a characteristic time period defined as

$$\tau = 3.7/N, \quad (C.5.4c)$$

and N is the Brunt–Vaisalla frequency given as

$$N = \left[\frac{g}{\theta_w} (\partial\theta_w/\partial z) \right]^{1/2} \quad (C.5.4d)$$

In the stable layer, plume spread is essentially due to self-generated turbulence which is caused by the momentum and/or buoyancy of the plume. The diffusion parameters in this layer are given as follows (Briggs 1975)

$$\sigma_{z_s} = \frac{a_1(F x^2)^{1/3}}{u_s} \quad \text{for } x/u_s \leq \tau, \quad (C.5.5a)$$

$$\sigma_{z_s} = a_2(F/N^2 u_s^2)^{1/3} \quad \text{otherwise,} \quad (C.5.5b)$$

$$\text{and} \quad \sigma_{y_s} = \frac{a_3(F x^2)^{1/3}}{u_s}. \quad (C.5.5c)$$

Where a_1 , a_2 and a_3 were determined to be 0.4, 0.96 and 0.67 respectively.

In the convective layer, results of Lamb (1978) and Willis and Deardorff (1978) are followed. For stacks lying within the mixed layer Lamb (1978) proposed the following:

$$\sigma_{y_c} = 1/3 (w_*/u_m)(x - x') \text{ for } (x - x') \leq h u_m / w_* \quad (\text{C.5.6a})$$

$$\sigma_{y_c} = 1/3 (w_*/u_m) H^{1/3} (x - x')^{2/3} \text{ for } (x - x') > H u_m / w_* \quad (\text{C.5.6b})$$

w_* is the convective velocity scale.

The shoreline fumigation model has been verified with data from the Nanticoke field study of May 28 to June 14, 1979 (Misra, 1980; Misra and Onlock, 1982). The model predictions agree well with the observed values. The parameters defining the state of the on-shore flow were the primary factors affecting the results of the model. The parameter which determines the height of the boundary layer, and hence, the location and size of the fumigation zone, was found to be important. Therefore care should be exercised in specifying its value. The evaluation of plume rise was also found to be critical.

C.6 Meteorological Conditions for Application of Shoreline Fumigation Model

The following meteorological conditions should be met to apply the shoreline fumigation model:

1. The wind direction should be onshore within a 140° sector centred on a line perpendicular to the shoreline near the source;
2. Convective conditions are diagnosed to occur overland;
3. The hours to be modelled are within the time period between April 15 and October 15.
4. The land temperature is more than 3°C higher than the lake temperature.

The parameter A in Eq.(C.3.1) may be calculated using Eq.(C.5.3). The lake temperature used in Eq.(C.5.3) may be approximated by the monthly average water temperature based on either remote sensing data or specific site measurements.

Alternatively, when acoustic radar data are available A may be calculated as

$$A = \frac{h_r}{(x_r^2 + h_o^2/A^2)^{1/2}}, \quad \text{C..6.1)}$$

where h_r is the boundary layer height measured by the acoustic radar located at a distance x_r downwind from the shoreline.

The other meteorological parameters required by the shoreline fumigation model are w_* , the convective velocity scale, and Γ , the lapse rate ($\partial\theta_w/\partial z$) over water. The value of w_* can be determined using the inland value of the convective boundary layer height, z_i , following the method described in Chapter 2. An average value of the stable lapse rate over water may be if local upper air data is not available. A value of $\Gamma = 0.0033^\circ\text{Cm}^{-1}$ is recommended, corresponding to $N = 0.01 \text{ s}^{-1}$.

Plume fumigation due to the presence of a thermal internal boundary must be included in the detailed modelling assessment of all elevated sources within 15 km of the lakeshore. This requires that the variation of the boundary layer height inland along the wind direction must be included in the modelling meteorological dataset. The boundary layer height used for the detailed modelling assessment is the value at the source location, $H(x)$. If the source emits above the site specific convective boundary layer (i.e. $z_s > H(x)$) the fumigation model is used to calculate downwind surface concentrations. If source release height is less than the local boundary layer height (or the emission is into a structure wake), for modelling purposes, no plume penetration above the thermal internal boundary layer is allowed during these hours. Since any material which escapes from the boundary layer would be quickly re-entrained into the deeper thermal internal boundary layer downwind from the source.

References

- Briggs, G.A., 1975: "Plume Rise Predictions" in Lectures on Air Pollution and Environmental Impact Analysis, Chapter 3, AMS, Boston, MA.
- Lamb, R.G., 1978: Numerical Simulation of Dispersion from an Elevated Point Source in the Convective Planetary Boundary Layer, Atmos. Env., 12, 1297–1304.
- Misra, P.K., 1980: Dispersion From Tall Stacks Into a Shore Line Environment, Atmos. Env., 14, 3967–4000.
- Misra, P.K., and S. Onlock 1982: Modelling Continuous Fumigation for the Nanticoke Generating Station Plume, Atmos. Env., 16, 479–489.
- Oke, T.J., 1978: "Boundary Layer Climates", Methuen and Co., New York, NY.
- Willis, G.E. and J.W. Deardorff, 1978: A Laboratory Study of Dispersion From an Elevated Source in a Convective Mixed Layer, Atmos. Env., 12, 1305–1313.

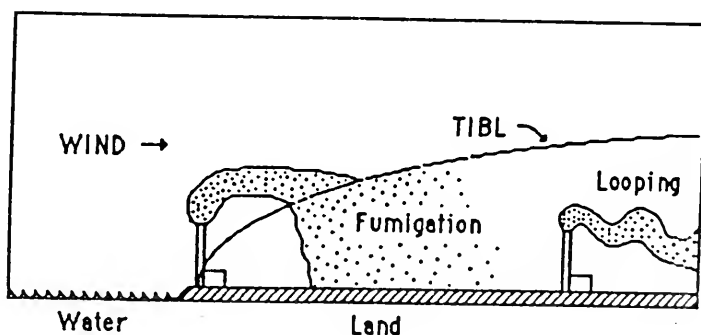


Figure C.1 Plume behaviour on a sunny, spring day as a function of location relative to the thermal internal boundary layer (TIBL). The plume emitted at the inland location essentially remains trapped within the TIBL (after Oke, 1978).

APPENDIX D

A GUIDELINE FOR PHYSICAL MODELLING OF SOURCES IN COMPLEX SETTINGS

This Appendix describes the criteria to define a setting sufficiently complex to recommend wind tunnel or water tank modelling (i.e. physical modelling) to determine contaminant concentrations. The basic requirements for adequate physical modelling and a conservative mathematical modelling alternative are also outlined.

D.1 Definition of a Complex Setting

The two settings for which physical modelling is recommended are:

1. A major development in a complex urban situation involving clusters of buildings or buildings with non-simple geometry;
2. Cases where a source is located in complex terrain.

Appendix A entitled "Modelling Air Quality due to Contaminant Releases from a Location On or Near a Building" provides guidelines to define a simple building. For accurate determination of air concentrations it is proposed that physical modelling be performed for a major development in a complex urban setting if the release height of the contaminants after compensating for stack-induced downwash are less than two times the height of the building or of nearby buildings, where "near" is defined in the Appendix A.

The second general circumstance for which physical modelling is recommended occurs when the terrain around a pollution source is complex. Significant terrain features near a source can affect the dispersion of material from that source and the range and frequency of occurrence of meteorological circumstances at the site.

It is proposed that terrain features are sufficiently complex to warrant physical modelling if both of the following conditions hold.

1. The release height of the contaminant is less than two times the maximum terrain height (h_{\max}). The maximum terrain height is defined as the

difference between the highest elevation (including tree tops) and the lowest elevation within a distance of 20 times the stack height or one kilometre, whichever is greater.

2. The gradient of terrain height with distance, Δx , from the source (i.e. $\Delta z/\Delta x$) be greater than 1/5. This criterion means that gently sloping terrain would not be considered to be sufficiently complex to recommend physical modelling. $\Delta z/\Delta x \geq 1/5$ is recommended as the terrain gradient criterion based on studies such as those by Briggs (1981) and Mickle et al. (1981) which show significant alterations of wind speeds and directions with terrain slopes of approximately 1/5 or 1/6.

Meteorological data are needed as input for either physical modelling or for running the set of the mathematical dispersion models described in this Document. Since the range and frequency of occurrence of meteorological data can be affected by terrain features such as ridges, these effects should be considered when compiling meteorological data for complex sites. The criteria for modifying the meteorological dataset are given in Part 3 of this Document.

D.2 Description of Physical Modelling

Physical modelling involves laboratory studies of dispersion using a scaled down model of a source and the terrain features. These studies can be performed in either a wind tunnel or in a water tank. Because a scale model of the source and its environment is used in the wind tunnel or water tank, it is necessary that the characteristics of the wind flow and the thermal regimes in the experimental setup correspond to the scale of the model. For example, spatial variations in the mean wind flow pattern caused by the complexity of the setting should be reduced in scale by the same factor that the model is scaled, compared to the actual site dimensions.

Several non-dimensional numbers, referred to as similarity numbers, are used to characterize the flow and thermal features in any fluid medium. These similarity numbers, which are combinations of the physical parameters of the system (i.e. flow speed, length scales, temperature, etc.) are constructed in such a way that they describe the physical processes which occur in the fluid. For wind tunnel or water tank studies of dispersion in

complex terrain, the important similarity numbers are the Reynolds, Froude and Prandtl numbers [Snyder (1981) and Snyder (1972)]. When working with scale models in wind tunnels or water tanks care must be taken that these similarity numbers should correspond to values in the atmosphere for the site in question. Snyder (1981) has provided a good description of the application of similarity numbers to wind tunnels or water tanks in a variety of circumstances.

A wind tunnel simulation of atmospheric dispersion has the advantage that the fluid medium is the same. Correspondingly it is easier to produce adequate similarity number matching. On the other hand, water tanks allow good flow visualization by using dyes in the fluid. Also, it is a little easier to simulate non-neutral atmospheric stability conditions in a water tank than in a wind tunnel, although it can be done in both experimental setups (Ueda et al (1986), Willis and Deardorff (1981) and Porek and Cermak (1984)).

There are wind tunnel facilities in the U.S. and Japan which can perform simulations for stable or convective conditions [Porek and Cermak (1984) and Ueda et al. (1986)]. it is recommended that a facility capable of simulating stable, neutral and convective conditions be used when modelling is done for a source in complex terrain. If only neutral simulations can be done it is recommended that mathematical model results for convective, neutral and stable cases described in this Document should be compared with physical modelling results for the neutral simulation, to decide on worst-case concentrations.

D.3 Alternative to Physical Modelling

For sites that are sufficiently complex to warrant physical modelling a conservative mathematical modelling alternative could be used by the proponent in place of physical modelling simulations.

For elevated sources a reduced plume height may be used to conservatively estimate ground level concentrations in complex terrain using a simple mathematical model. Since complex terrain situations have the potential to affect the centreline height of the plume, it is recommended that ground level concentrations be calculated using a plume height equal to half the centreline plume height calculated for flat terrain. The flat terrain plume height is calculated as outlined in Chapter 3. Formulae for deriving concentrations as a

function of distance downwind and height above the source location ground level are provided in Chapter 4 for stable and neutral conditions. It is recommended that ground level concentrations at the height of the varying terrain be calculated for receptors within a radius defined by the nearest location, where the terrain height is greater than or equal to half the flat terrain plume height. It is further recommended that the maximum radius for which these receptor calculations need be performed is 100 times the stack height.

Maximum ground level concentrations would then be derived as the larger of the maximum receptor concentration for neutral and stable conditions outlined above or convective calculations for an elevated source in flat terrain as described in Chapter 4.

References

Briggs, G.A., 1981: Canopy Effects on Predicted Drainage Flow Characteristics and Comparisons with Observations. Fifth Symposium of Turbulence, Diffusion and Air Pollution, Atlanta, AMS, Boston, MA.

Mickle, R.E., J.R. Salmon, P.A. Taylor, H.a. Teunissen, and J.L. Walmsley, 1981: Boundary Layer Flow over Kettles Hill, Alberta. Fifth Symposium of Turbulence, Diffusion and Air Pollution, Atlanta, AMS, Boston, MA.

Porek, M., and J.E. Cermak, 1984: Wind Tunnel Simulations of Diffusion in a Convective Boundary Layer. *boundary-Layer Meteor.*, 30, 431-455.

Snyder, W.H. 1972: Similarity Criteria for the Application of fluid Models to the Study of air Pollution Meteorology. *Boundary-Layer Meteor.*, 3, 113-134.

Snyder, W.H., 1981: "Guideline for Fluid Modelling of Atmospheric Diffusion." EPA-600/8-81-009 U.S. Environmental Protection Agency, Research Triangle Park, N.C., 185 pp.

Ueda, H., S. Komori and K. Fukui, 1986: A Laboratory Experiment on Lateral Diffusion of Scalar Quantities in the Stratified Surface Layer. *Atm. Environ.*, 20, 757–766.

Willis, G.E., and J.W. Deardorff, 1981: A Laboratory Study of Dispersion from a Source in the Middle of a Convective Mixed Layer. *Atm. Environ.*, 15, 109–117.

APPENDIX 8-3

MODELLING SCHEDULE

**METHODOLOGY FOR THE DETERMINATION OF
METEOROLOGICAL PARAMETERS REQUIRED FOR
THE FULL AIR QUALITY MODEL CALCULATIONS**

Table of Contents

1 Introduction	1
2 Determination of the Necessary Boundary Layer Parameters	2
3 Selection of Suitable Raw Meteorological Data	9
4 Meteorological Data Control and Initial Screening	9
4.1 Surface Data	10
4.2 Upper Air Data	12
5 Creation of Regulatory Model Input Dataset	12
6 Calculation of the Boundary Layer Parameters	20
7 References	22
8 Modification of Regional Datasets to Reflect Local Conditions	23
8.1 Decision Whether Regional Data Should be Modified	23
8.1.1 Locations that Require Special Consideration	23
8.1.2 Comparison of Local Dataset with Regional Dataset	25
8.1.3 Comparison of Wind Statistics	26
8.2 Procedures for Modifying the Regional Dataset	28
8.2.1 Lakeshore, Urban and Wind Channelling Locations	28
8.2.2 All Locations	30

1 Introduction

MOE has developed a set of air quality models suitable for regulatory applications. These models can be applied to a range of possible meteorological conditions for the assessment of local air quality due to sources of a contaminant. The modelled concentrations can then be compared with established hourly, 24-hourly, or annual air quality standards.

The running of these models requires no special meteorological data. As listed in Section 3, only hourly observations of wind speeds and directions, air temperature, cloud and snow cover, and daily early morning upper air temperature soundings are needed as input. These data are readily obtainable as they are routinely collected from representative sources.

The users have two options when selecting a meteorological dataset to use in the assessment of their sources(s): i) they may use a regionally representative dataset available from MOE, or ii) they may develop their own dataset from suitable raw data following the methodology given in the document. Section 2 describes the theoretical relationships that relate the required boundary layer parameters to the routinely available meteorological data.

In some cases at the proponent's site, local effects may sufficiently modify the meteorological conditions that the regionally representative datasets cannot be directly applied at this site without consideration of these local effects. Examples of such cases would be lakeshore locations, sites in an urban core, and sites situated where winds are significantly channelled by the local terrain. Two options are given when considering site specific meteorological conditions: i) the proponent may undertake to collect suitable site specific raw data, or ii) the proponent can use Appendix A of this document as a guideline for including several important local effects into the regional dataset. These quality controlled regional datasets will be available from MOE.

2 Determination of the Necessary Boundary Layer Parameters

The routine application of air quality models requires that the information needed to perform model calculations be readily available. First the required meteorological model input information will be described and then methods for determining the required boundary layer parameters are outlined.

(a) The Required Meteorological Information

The chart shown below summarizes the necessary meteorological data:

(i) surface heat flux		
$H_o > 0$ Convective	$H_o = 0$ Neutral	$H_o < 0$ Stable
i) boundary layer height z_i	ii) wind speed u	ii) wind speed u
iii) wind speed u	iii) surface roughness length z_o	iii) surface roughness length z_o
iv) temperature T_a	iv) temperature T_a	iv) temperature T_a
v) surface roughness length z_o		

The basic meteorological data used by the models are: u , the period (30 minutes or 1 hour) average wind speed at a height of approximately 10 meters (anemometer level); T_{ao} , the period average ambient surface temperature; cc , the cloud cover as a fraction of the total sky; the ground snow cover; and, if available, the boundary layer height z_i . The surface roughness length, z_o , may be approximated as 1/30th of the height of the roughness elements such as buildings or trees. Table 2.1 lists z_o for various surfaces.

TABLE 2.1

ROUGHNESS LENGTHS FOR VARIOUS SURFACES	
Surface	z_0 (cm)
Very smooth (ice, mud flats)	0.001
Snow	0.005
Smooth sea	0.02
Lawn, grass up to 1 cm high	0.03
Lawn, grass up to 5 cm high	1-2
Lawn, grass up to 50 cm high	4-9
Fully grown root crops	14
Forest	50-100
Urban Core	100

After Pasquill (1974) and Seinfeld (1975)

Given the location (latitude and longitude), the date and time period of interest, the surface heat flux H_o may be calculated based on the assumption that it is proportional to the net solar radiation plus a small correction for the long wavelength loss of heat from the surface. Cloud cover reduces the net solar radiation reaching the surface and, also, decreases the long wave losses. The calculations follow the formulation reported by Maul (1982):

$$H_o = \alpha R + H_L, (Wm^{-2}) \quad (1)$$

where R is the incoming solar radiation and depends on the time of day (t in decimal hours Greenwich Mean Time, GMT), the latitude of the source (L_R in radians), the longitude of the source (L_D in degrees), the day of year (d given as the Julian day, numbers 1 to 365 or 366) and the fractional cloud cover of the sky (c in number of eights).

$$R = 950\beta(\cos(\phi)\cos(r)\cos(L_R) + \sin(\phi)\sin(L_R)), (Wm^{-2})$$

where: $r = \pi(t - t_n)/12$ and $t_n = 12 + L_D/15$ is the local noon time (GMT).

and: $\phi = \text{ARCTAN}(0.4348 \sin(\pi(d-78)/180))$.

β is the radiation reduction factor for the incoming solar radiation due to cloud cover. Table 2.2 lists β for given amounts of cloud cover (sky cover).

Table 2.2

Cloud Cover Reduction Factors for Incoming Solar Radiation*		
Sky Cover Percent	Oktas (cc)	β
0.0	0	1.00
12.5	1	0.89
25.0	2	0.81
37.5	3	0.76
50.0	4	0.72
62.5	5	0.67
75.0	6	0.59
87.5	7	0.45
100.0	8	0.23

* After Maul (1982)

This calculation only applies between local sunrise and sunset, that is, for values of t between

$$t_{\text{rise}} = t_n - (12/\pi) \cos^{-1} (-\tan(\phi) \tan(L_R))$$

$$\text{and } t_{\text{set}} = t_n + (12/\pi) \cos^{-1} (-\tan(\phi) \tan(L_R)).$$

The factor α in equation 1 is a function of the local surface ($\alpha = 0.35$ is assumed in the model) and it is an empirical proportionality factor between the incoming solar radiation and the surface heat flux. Note that when there is snow cover it is assumed that $\alpha = 0$. The above values are for typical rural lands.

$$H_L = -3. (8.5 - cc)$$

is the long wavelength heat loss at the surface.

Alternatively, H_0 may be determined from measurements of net solar radiation or surface fluxes.

The convective boundary layer height, z_i , may be estimated using the nearest rawinsonde temperature versus height profiles when $H_0 > 0$. Following the method of Holzworth (1967) z_i is calculated as the height above the ground at which the dry adiabatic extrapolation of the surface level temperature (T_s) intersects the 1200 GMT vertical temperature profile (700 EST).

When $H_0 < 0$ the boundary layer height is calculated based on the wind speed and the Monin-Obukhov length scale. The neutral boundary layer height may be calculated based on the wind speed.

The surface (anemometer level) wind speed, u (m s^{-1}), the wind direction and the surface temperature, T_s ($^{\circ}\text{K}$), may be obtained from measurements taken near the source site by MOE, AES or other meteorological monitoring stations operated in an acceptable manner.

(b) Determining the Boundary Layer Parameters

The required boundary layer parameters are summarized below by meteorological category:

Convective		Neutral		Stable	
i)	Convective velocity scale w_*	i)	friction velocity u_*	i)	friction velocity u_*
ii)	Monin-Obukhov Length scale L	ii)	neutral boundary layer height H	ii)	Monin-Obukhov length L
iii)	friction velocity u^*			iii)	stable boundary layer height H

It is assumed that when the surface heat flux is greater than 5 W m^{-2} convective eddies are set up in the boundary layer. The convective boundary layer parameters required in the continuous source models are:

the convective scaling velocity,

$$w^* = (gH_o Z_i / (\rho c_p \bar{T}))^{1/3} \quad (2)$$

the Monin-Obukhov length scale,

$$L = -u^{*3} \bar{T} \rho c_p / (g \kappa H_o), \quad (3)$$

$$\text{and } u^* = \kappa u / (\ln(z_a/z_o) - \Phi(z_a/L)) \quad (4)$$

the friction velocity, where

$$\Phi(z_a/L) = 2 \ln((1 + q)/2) + \ln((1 + q^2)/2) - 2 \text{ARCTAN}(q) + \pi/2$$

$$\text{and } q = (1 - 15z_o/L)^{1/4}.$$

\bar{T} is the mean boundary layer temperature and is calculated from the near surface temperature T_a , the boundary layer depth z_i , and by assuming the temperature lapse rate is approximately adiabatic, hence,

$$\bar{T} = 1/2 (2T_a - 0.0098 z_i).$$

ρ is the density of air (approximately 1.2 kg m^{-3}), c_p is the specific heat of dry air at constant pressure ($c_p = 1005 \text{ J/kg}^\circ\text{K}$) and g is the acceleration due to gravity (assumed to be 9.81 m s^{-2}). The von Karman constant, κ , is set to 0.35. Z_a is the wind sampling height.

When the wind speed is greater than $6 w^*$, convective scaling is no longer appropriate for modelling (due to the increased importance of vertical wind shear). In these windy cases the boundary layer is assumed to be a neutral boundary layer. If the wind speed is less than $1.2 w^*$, the assumption that the concentration is independent of time (steady state assumption) is no longer valid. Modelling the concentration for these calm periods is not within the scope of currently available simple models.

The boundary layer is assumed to be stable if the surface heat flux is less than -5 W m^{-2} . Under these conditions the boundary layer parameters required are:

the Monin-Obukhov length scale, L , and the friction velocity,

$$u = \kappa u^* / (\ln(z_u/z_o) + 4.7(z_u/L)). \quad (5)$$

When the Monin-Obukhov length scale, L , is plotted as a function of u^* based on measurements in a stable boundary layer it is observed (Venkatram, 1980b) that there is an empirical relationship between L and u^* . Venkatram,(1980b) parameterized the Monin-Obukhov length as

$$L = 1100u^{*2} \quad (6)$$

When the wind speed and hence u^* is small Venkatram's empirical fit is no longer valid (i.e., there are no real solutions to Eqs.(5) and (6)). Wind speeds which are less than the minimum necessary for real solutions are assumed to be calm. For modelling purposes, L is calculated using the minimum wind speed for which real solutions to Eqs. (5) and (6) exist. u^* is then calculated from Eq. (5) using the observed wind speed.

When the Monin-Obukhov length scale exceeds 500 meters it is proposed that for modelling purposes the boundary layer can be assumed to be a neutral boundary layer.

Stable boundary layer heights may be calculated using the other stable boundary layer parameters and Nieuwstadt's (1981) formulation.

$$H/L = 0.3u^* (1 + 1.9H/L) / (f_c L) \quad (7)$$

where f_c is the Coriolis parameter. (It is assumed that $f_c = 10^{-4} \text{s}^{-1}$).

This equation reduces to the model of Brost and Wyngaard (1978) for L approaching zero and to the Tennekes (1973) neutral model for very large L . i.e.,

$$H = 0.3u^* / f_c \quad (8)$$

The boundary layer is assumed to be a neutral boundary layer when there is negligible surface heat flux or when there are high winds. For modelling purposes it is proposed that the heat flux be assumed to be negligible if its value does not exceed 5 W m^{-2} and is not less than -5 W m^{-2} . The only other boundary layer parameter required in this case is the friction velocity,

$$u^* = \kappa u / \ln(z_a/z_o) \quad (9)$$

3 Selection of Suitable Raw Meteorological Data

Raw data necessary as input for the air quality models consists of observations of:

- hourly 10 m wind speed and direction
- hourly screen level temperature
- hourly cloud cover
- hourly snow cover
- 1200 GMT or early morning upper air temperature soundings to 3 km.

These regional data sets must be for a contiguous period of at least 1 year and all data must be sampled at essentially the same site. A higher level wind speed value can also be used by the model for transport purposes if such tower data is available. It should be noted that large datasets of this nature sometimes have potential deficiencies in terms of data quality or data gaps. These problems will be addressed in Section 4.

If the proponent collects his own data, then the standard procedures for observing, recording, and reporting weather conditions in accordance with internationally recommended procedures as established by WMO must be followed. These detailed standards may be found in MANOBS (AES, 1977 + Amendments) for surface data and MAN-LJPP (AES, 1975 + Amendments) for upper soundings. Instrument manuals are also available from AES which describe the standards of instrument performance and siting procedures. If these standards are not followed, data sampled under slightly different protocols will require approval from the MOE.

4 Meteorological Data Control and Initial Screening

Once the meteorological data are acquired, either from outside sources or by way of the proponents own observations, there is always a necessity to screen the data for obvious errors in sampling.

Raw data even from AES, MOE, or the National Weather Service (NWS) cannot be assumed to be error free as problems could have occurred with faulty data collection, instrument failure, or even with archiving procedures.

When small gaps occur in the data, interpolation of some fields is considered appropriate if the gap in the record does not exceed 12 hours. Temperature and wind speed may be interpolated linearly.

4.1 Surface Data

Errors in the surface data could occur with any of the required meteorological parameters. The discussion below focuses on points to be aware of during the initial screening that should be carried out on the input parameters of wind direction, wind speed, surface (screen level) air temperature, cloud cover, and snow cover.

a) Wind Speeds and Direction

The winds should be measured at the 10 m anemometer level. The unit of measurement is usually knots, although the regulatory model uses meters per second as the unit of wind speed for its calculations. Hourly wind speeds from A.E.S. stations are reported as a one-minute mean. It should be noted, however, that synoptic wind speeds are reported as a ten-minute average in the interval prior to observation time.

Wind direction is reported to the nearest 10 degrees.

As a quality check of possible errors in the wind records, wind speeds should not vary highly from one hour to the next, nor should wind directions change considerably in this same time period. The use of minute-averaged winds is meant to reduce the effect of errors from the gustiness of wind speed variations. Similarly, wind direction changes from hour to hour are relatively smooth except for times of frontal passages or light wind speeds. If there is doubt regarding the authenticity of the data, any special notes or comments to the weather records should be checked and the surface weather maps consulted. Wind gusts and frontal passages are routinely noted in the records.

Consistently high or low wind speeds may indicate possible errors in units of measurement or units used in the modelling, improper location of the anemometer, poor instrument calibration, or archiving errors in transferring the data from source to archives to modelling data input files.

b) Air Temperature

Surface air temperatures are the dry bulb values recorded with thermometers located in a Stevenson screen according to the AES/WMO standards of temperature measurements. Temperature observations are recorded to the nearest tenth of a degree Celsius. As with wind observations, the hourly variation in air temperature should not be too large except possibly during times of frontal passage.

Consistently high temperatures may indicate improper units of measurement, poor instrument calibration, poor screening of the thermometer, archiving errors, or problems in data transfer.

c) Cloud Cover

In the hourly records, cloud fractional coverage of the sky is reported in tenths with the total coverage or opacity given as the sum of each layer amount and opacity. If the sky is obscured by any atmospheric phenomenon (clouds, dust, blowing snow, precipitation, etc.), it is assumed to be totally opaque. Insofar as the transfer of radiation from the ground surface, this may be an acceptable representation.

The synoptic records, however, report the fraction of sky coverage in oktas (eighths). The regulatory model also uses this convention, so that any hourly data reported in tenths must be converted to oktas for use in the model.

Cloud cover can never exceed 10 tenths or 8 eighths. One common problem is the determination of the amount of sky cover at night as the darkness prevents an accurate determination of this parameter. Hence at the time of sunrise, when the lighting conditions provide a better venue for sky observations, the records may show a sudden change from the conditions reported throughout the night.

d) Snow on the Ground

The hourly observations do not normally contain data on the presence or absence of Snow on the Ground (SOG). This is a requirement for the modelling and must be added to the standard dataset. For Canadian stations, the AES Digital Archives contain an AM snow depth value given in whole centimeters. For U.S. data, the SOG can be determined by visual examination of the daily precipitation area and amount maps published by the National Oceanographic and

Atmospheric Administration (NOAA), and using the 1" snow depth isopleth as a guide for snow coverage. It should be noted that urban areas can lose their snow cover more quickly than indicated at rural or suburban sites.

4.2 Upper Air Data

As part of the raw data used to determine the mixing layer height and dispersion climatology for a site, the final requirement is for vertical temperature profiles observed in the early morning on a daily basis for a year. If a radiosonde profile is to be used, it should be the 1200 GMT sounding, and needs to extend approximately 3000 m above the ground to be useful.

Large vertical gradients of temperature (over the distance of tens or hundreds of metres) would require a more detailed examination of possible errors in the profile. Other measurement parameters such as dewpoint, wind speeds and directions, heights, and pressures should be checked if the full radiosonde profile is available.

In routine operations, there is expected to be a certain percentage of missing or unusable soundings. In the application of combining the upper air data with the surface temperatures to derive the mixing heights, there may be some discrepancies between the sounding's ground level temperature and the screen-measured surface air temperature.

The surface and upper air model input datasets provided by the Ontario Ministry of the Environment have undergone extensive scrutiny to eliminate as many errors as possible. The checking procedures which were applied to the raw data and the initial processing to produce the regional datasets are outlined below.

5 Creation of Regulatory Model Input Dataset

The section describes how the Regulatory Model input dataset can be created, using as an example of initial raw data observations archived by the MOE MDAS system.

In order to produce the final MOE Regulatory Model input datasets, the data passed through a number of processes. These are described below and are illustrated in the flowchart of Figure 5.1.

a) Surface Weather Elements

The monthly surface data for each station were extracted from MDAS SA data. The resulting datasets were then used to produce a set of time series plots for each of the surface weather elements of pressure, air temperature, and wind direction and speed. These plots were examined in conjunction with a detailed list of extracted observations which had large variations in the parameters from one hour to the next. The acceptable limits for hourly variations were as follows: a 2.0 mb pressure change; a 5 °C air temperature change; a 20 knot wind speed change; and a 200 degree wind direction change. Using the time series plots as a visual indicator of variations in the data and the detailed listing to provide the date and hour, the invalid data were then flagged by editing the monthly datasets.

It should be noted that these limits of hourly variations are only guidelines to be used in an objective screening of the data. These variations can and do occur in nature and a manual check of these observations should still be carried out by a competent meteorologist or meteorological technician to ensure that the data is indeed faulty and needs correction.

b) Snow on Ground

For the regional datasets, both Canadian and U.S., SOG values were created for the complete time period by extraction of this data as described in Section 4.1. These data were included in the model surface dataset either as a '0' for no SOG, or '1' for the presence of SOG at each date and time.

Figure 5.1 Procedures for producing the input dataset for the 1988 MOE Regulatory Model

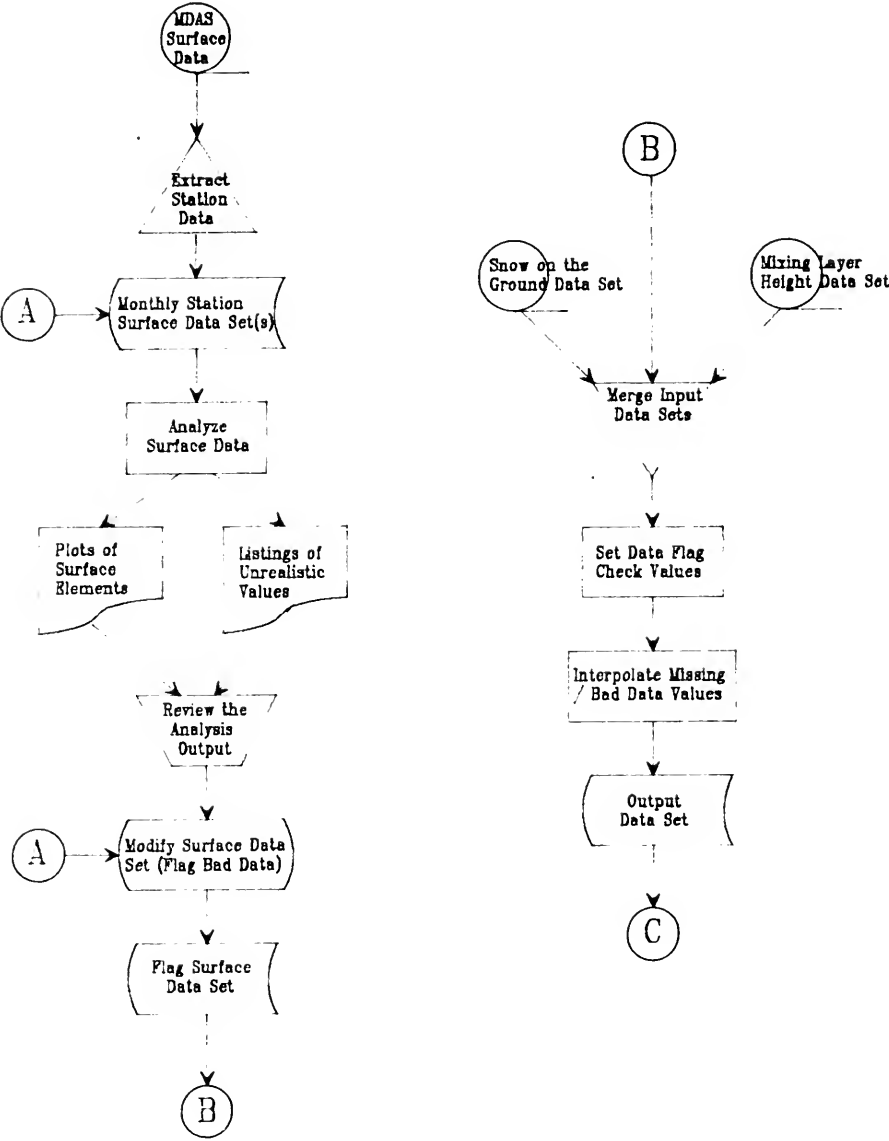
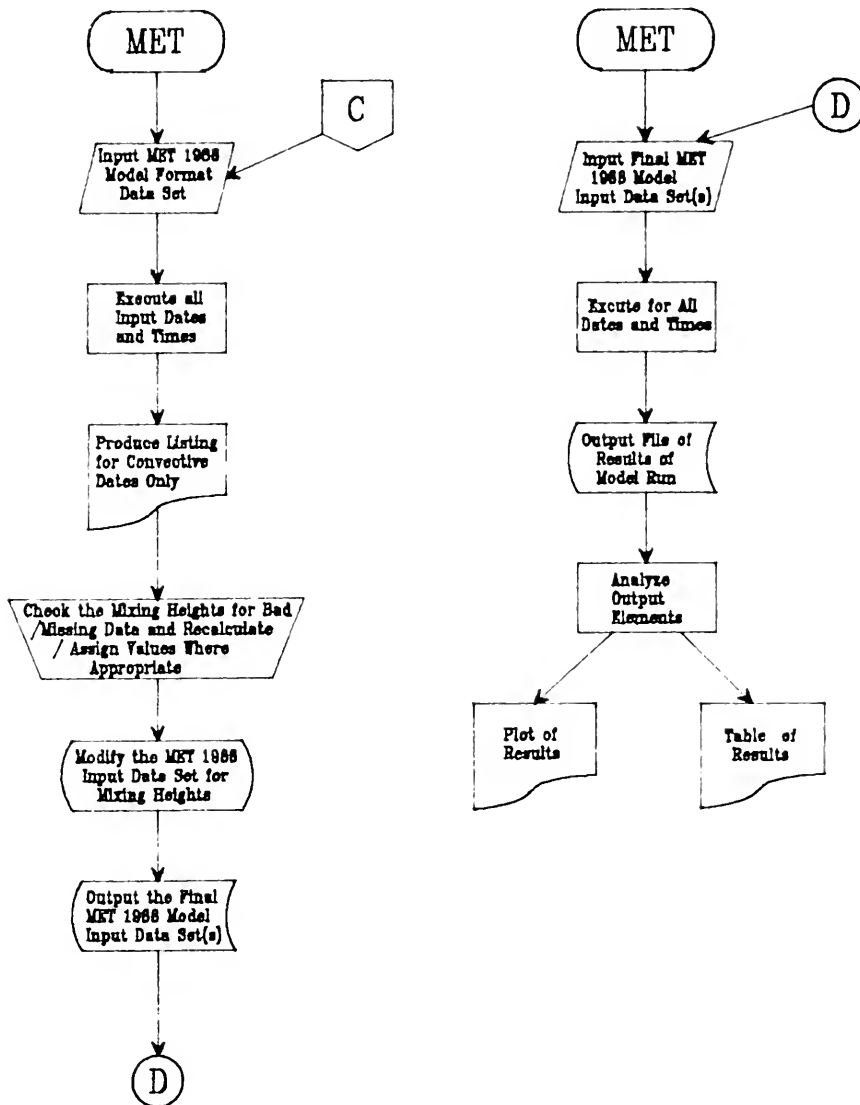


Figure 5.1 Continued ... Procedures for producing the input dataset for the 1988 MOE Regulatory Model



c) Mixing Layer Height Dataset

The hourly convective boundary layer height, also referred to as the Mixing Layer Height (MLH), is a requirement to determine the dispersion climatology of the site. This is not a routinely measured parameter, and must be inferred from other routinely collected data based on certain physical assumptions. There are a number of methods for deriving this parameter (e.g., slab calculations), but the method selected by MOE is that of Holzworth (1967) for use with the proposed regulatory models.

The assumptions and procedures have been described in Section 2. To carry out this calculation, the required data are the hourly surface temperature measurements and the upper air profile of temperature, taken from the closest available upper air sounding station, and extending up to approximately 3 km in altitude.

The depth of the mixed layer may also be determined using acoustic sounder data where available. This information can be useful near lakeshores where a comparatively shallow boundary layer is produced when the flow is from a cold lake to a warm land surface.

Creation, Merging, Flagging and Interpolation of Surface Datasets

Once the surface dataset has been checked and flagged for invalid data, and the SOG and MLH datasets have been created, the datasets are merged by date and time. A data flag is defined (see Table 5.1) for each date and time, and an interpolation to replace gaps and invalid records in the surface data takes place.

Table 5.1

Data Check Flag Description	
Parameter	Data Flag Value
Initially	0
Pressure missing Pressure invalid	+ 1 + 2
Air Temperature missing Air Temperature invalid	+ 3 + 6
Total Cloud Amount missing Total Cloud Amount invalid	+ 10 + 20
Wind Direction missing Wind Direction invalid	+ 30 + 60
Wind Speed missing Wind Speed invalid	+ 100 + 200
Mixing Layer Height missing Mixing Layer Height invalid	+ 300 + 600

Subsequent to the checks for invalid surface data the steps taken to produce the final MOE Regulatory Model input dataset are as follows:

- i. Merge SOG data with surface data by date and time;
- ii. Merge MLH data with surface data by date and time;
- iii. Define a data flag value for each date and time (see Table 5. 1);
- iv. Convert surface wind speed to m s^{-1} ;
- v. Interpolate parameters;
- vi. Write parameters for use in M.O.E. Model.

The MOE Regulatory Model input dataset format is given in Table 5.2, and the output format in Table 6.1 respectively.

Table 5.2

MOE 308 Regulatory Model (1988) Input Format			
Field	Position	Format	Description
Year	1-2	I2	
Month	3-4	I2	
Day	5-6	I2	
Hour	7-8	I2	
Alternate wind speed	17-22	F6,3	Metres/second
Air Temperature	23-26	I4	Degrees C
Wind Direction	27-40	E14.8	Degrees
Wind Speed	41-54	E14.8	Metres/second
Cloud Amount	55-58	I4	8ths
Snow Cover	59-62	I4	(0=NONE, 1=YES)
Mixing Layer Height	63-66	I4	Metres
ldata	67-70	I4	Data Check Flag Code

The MOE meteorological preprocessor is then run for each station to produce a set of convective dates and times. These dates are then checked for any missing or bad mixing layer height values. The checking procedures for the convective mixing heights can be summarized as follows.

- i) Ensure that mixing heights do not decrease during a given day. If so, the decreasing mixing height value is replaced with the maximum mixing height value that occurred before these values started to decrease.
- ii) Check the indicated "-99" values listed for the mixing heights, for the following reasons:
 - a) Upper air soundings may be missing for that day. To ensure that this was the case, check the corresponding raw upper air data files.
 - b) The surface air temperature may have been originally missing. If the IDATA column indicates an interpolated temperature, the mixing height is calculated by using the interpolated surface temperature value.

c) Surface temperatures may be colder than the lowest level temperature of the upper air profile. In these cases, the mixing height is fixed at 50 m for rural areas and 100 m for urban regions.

d) The mixing height may be higher than 3,000 m. It can be checked also by examining the trend in the values of mixing height in the preceding hours.

The bounds on the calculated mixing height value should also be between 50 and 3,000 m as these are the minimum and maximum values imposed in the MLH.

These above checks should be manually carried out by a meteorologist or a competent meteorological technician. If it is found that corrections can be made, the model input datasets are then modified with the appropriate changes to mixing layer height and data flag value (if necessary).

The resulting dataset is the final input dataset produced, and is used to generate the boundary layer parameters to be analyzed for each station.

6 Calculation of the Boundary Layer Parameters

With the merging of the surface data and the mixing height file, the meteorological module for the proposed small scale regulatory model is run to produce the parameters listed in Table 6. 1.

Table 6.1

MOE Regulatory Model Output Format			
Field	Position	Format	Description
IYR	1-2	I2	Year
TMIH	3-4	I2	Month
IDY	5-6	I2	Day
IHR	7-8	I2	Hour
UALT	9-14	F6.3	Alternate Wind Speed (m/sec)
ITEMP	15-17	I3	Surface Temperature (* C)
WDIR	18-23	F6.2	Wind Direction (degrees)
WSPD	24-29	F6.3	Wind Speed (m/sec)
ICLD	30-31	I2	Cloud Cover (8ths)
ISOG	32	I1	Snow on the Ground (0=NONE,1=YES)
MINHT	33-36	I4	Mixing Layer Height (m)
IDATA	37-39	I3	Data Check Flag (code)
RLAT	40-44	F5.2	Latitude (decimal degrees)
RLON	45-50	F6.2	Longitude (decimal degrees)
ZO	51-57	F7.5	Surface Roughness(m)
SUNRISE	58-62	F5.2	Local Sun Rise
SUNSET	63-67	F5.2	Local Sun Set
HO	68-74	F7.2	Surface Heat Flux (w m ⁻²)
IFLUX	75	I1	Boundary Layer Stability Flag (1 = Convective, 2 = Neutral,3 = Stable)
HCBL	76-82	F7.2	Height of Convective Boundary Layer (m)
HNBL	83-89	F7.2	Height of Neutral Boundary Layer (m)
HSBL	90-96	F7.2	Height of Stable Boundary Layer (m)
U10	97-102	F6.3	Wind Speed at 10 metres (m/sec)
L	103-111	F9.3	Monin-Obukhov Length (m)
USTAR	112-118	F7.4	Friction Velocity (m/sec)
WSTAR	119-125	F7.4	Convective Velocity Scale (m/sec)
WRND	126-129	F4.1	Wind Direction Randomization Amount (degrees)
RU	130	A1	Rural/Urban Setting Flag ('R'= rural, 'U'= urban)
IFLAG	131-133	I3	Condition Flag for Parameter Calculation

There should be a judicious selection of the roughness parameter z_0 to represent the land use surrounding the site in question. Representative values of z_0 are given in Table 2.1 for different surfaces.

The proponent should use the average surface characteristics either out to the receptor of interest or in the vicinity of the proponents source complex (i.e. a radius of ~1.5 km). For buildings and trees a surface roughness of $1/30^{\text{th}}$ of the height of these features may be used.

Internally in the program, to calculate the boundary layer parameters checks are made on the values of L and Z_i for convective hours to ensure that the results are consistent. The maximum ratio L/Z_i is $1/2$. If the heat flux is greater than 20 watts m^{-2} and $L/Z_i > 1/2$ then Z_i is set to $2L$. If the heat flux is less than or equal to 20 watts m^{-2} and $L/Z_i > 1/2$ then L is set to $Z_i/2$.

Wind directions are randomized within a range of $+4^\circ$ to -5° relative to the given direction accurate to the nearest 10° . This avoids artificial concentration spikes for long time period average concentrations.

To review the results, it is advisable to carry out an analysis of the statistics (such as means and histograms) of the boundary layer parameters to ensure that the results are within reasonable bounds or as a comparison with other regional datasets. Differences between sites should have a physical basis of explanation.

7 References

- Atmospheric Environment Service, 1977: MANOBS: Manual of Surface Weather Observations + Amendments. Environment Canada, Downsview.
- Atmospheric Environment Service, 1975: MANUPP: Manual of Upper Air Observations + Amendments. Environment Canada, Downsview.
- Brost, R.A. and J.C. Wyngaard, 1978: A model study of the stably stratified planetary boundary layer. *J. of Atmos. Sci.*, 35, 1427-1440.
- Holzworth, G.C., 1967: Mixing depths, wind speeds and air pollution potential for selected locations in the United State, *J. Applied Met.*, 6, 1039-1044.
- Maul, P.R., 1980: "Atmospheric Transport of Sulphur Compound Pollutants" C.E.G.B.Report MID/SSD/80/0026/R, pp 194.
- Nieuwstadt, F.T.M., 1981: The steady-state height and resistance laws of the nocturnal boundary layer: Theory compared with Cabauw observations, *Boundary Layer Meteor.*, 19, 3-17.
- Pasquill, F., 1974: "Atmospheric Diffusion", 2nd Edition, J. Wiley and Sons, New York, pp 429.
- Seinfeld, J.H., 1975: "Air Pollution", McGraw-Hill Inc., New York, pp 523.
- Tennekes, H., 1973: Similarity laws and scale relations in planetary boundary layers, in "Workshop on Micrometeorology". AMS, Boston, MA., pp 392.
- Venkatram, A., 1980b: Estimating the Monin-Obukhov length in the stable boundary layer for dispersion calculation, *Boundary Layer Meteor.*, 19, 481-485.

APPENDIX

MODIFICATION OF REGIONAL DATASETS TO REFLECT LOCAL CONDITIONS

Whenever full modelling is required, a regional meteorological dataset is to be used. MOE will recommend which of the quality controlled regional datasets is most representative of the site region. The possibility of modification of this dataset for local conditions must be considered. This entails the examination of local meteorological data which is representative of the more immediate site area and consideration of local site-specific effects such as lakeshore and/or urban location and/or wind channelling by hills and valleys. The local meteorological dataset should meet AES/MOE observation standards.

8.1 Decision Whether Regional Data Should be Modified

The regional meteorological data should be modified for local conditions if the site fails within the special designation of lakeshore, urban or wind channelling setting. Modification is also required if the locally representative meteorological data deviates significantly from the regional data as to the surface (10 m) wind speed or wind direction. Consideration of the differences between the regional and local meteorology are discussed in the sections which follow. The proponent has the option of undertaking the modification of the regional dataset or of first comparing the two sets of data as outlined below in Section 8.1.2, to determine whether modification is necessary.

8.1.1 Locations that Require Special Consideration

Lakeshore

A site is designated as a lakeshore location when the local meteorology is expected to be influenced by the proximity of the lake. All sites within 15 km of one of the Great Lakes (including Lake St. Clair) or Lake Simcoe, are to be regarded as lakeshore sites. For smaller lakes the local effect is not considered to be significant, generally. However, in some

instances, the lake-to-land temperature difference in combination with sufficiently long over-water fetch from a persistent specific wind direction can influence the local meteorology and, as a consequence, affect the 24-hour concentration values. These conditions are to be considered on a case by case basis.

Urban

A site is designated as an urban site when the local meteorology is expected to be subject to urban heat island effects. Any site that is within the municipal boundaries of a city (population 25,000 or more and having a concentrated urban core) is considered to be an urban site. Further, if a 1 km radius of the site is within these boundaries, the site is designated as urban.

Hill or Valley

A site is designated as being subject to valley channeling when the local wind conditions are expected to be influenced by a significant topographic feature such as a hill or valley or a ridge, e.g., the Niagara escarpment. The influence of a hill or valley on local wind patterns depends on the horizontal extent of the feature, its slope and the atmospheric stability. For neutral atmospheric conditions the influence extends to a distance about twice the horizontal extent of the feature. For an isolated hill of height H , the influence would be within a radius horizontally of 2 times H from the top of the hill. For an elongated feature of horizontal extent L , the influence would be to a horizontal distance of 2 times L from the top of the feature. The influence of a long ridge such as the Niagara Escarpment could extend to 15 km from the top of the ridge. The distance criteria for neutral conditions given here will be used for determining distances within which sites are considered to be classified as subject to valley channeling of winds, for all stabilities. Some locations may be a combination of two or all three of the special designations. For example, urban sites between the escarpment and Lake Ontario are subject to the conditions of urban, lakeshore and valley wind channelling.

8.1.2 Comparison of Local Dataset with Regional Dataset

Examination of locally representative meteorological data for significant differences from the regional dataset is to be undertaken for all cases that require full modelling, unless the proponent decides to perform the modification without first determining whether it is required by the differences that exist between the two sets of data.

The choice of the local dataset should be justified as to whether or not the surface wind data is representative of the local site. Because the model is less sensitive to surface temperature deviations, modification of surface temperature is not included.

Hourly meteorological data is required for surface (10 m) wind speed and direction, reported to the nearest 10 degrees. This restricts the choice of local datasets to those from AES principal climatological stations (synoptic and aeronautical equipped with the standard type U2A wind equipment) or their equivalent in other networks, e.g., MOE. A list of suitable AES and MOE stations for Ontario is given at the end of this Appendix. If the local site is near the border of Quebec, Manitoba or a state of the U.S., there may be a local dataset from one of these jurisdictions which would be more representative of local conditions than any of the Ontario datasets.

For a site where the proponent has been monitoring meteorological data for some years, the proponent may wish to use this data. Provided that the monitoring procedure meets AES/MOE standards and approval, this hourly data can be used as the local dataset. The local dataset for comparison should be for the same year as the regional data set used. Comparison of annual statistics and in some cases, seasonal and night/day statistics, is required. The criteria for requirement of modification of the regional data are given below in Section 8.1.3.

Sites for which Local Data are Not Available

If local data is not available for a year with a regional data set, meteorological data for the most representative of the regional (upper air) stations is to be obtained by the proponent for a year for which local data is available. The regional dataset is to be prepared by the

proponent according to the procedure described in previous sections of this document, but including modification of the regional dataset using local surface data as described below in Section 8.2.

If there is reason to believe that local conditions are significantly different from regional, (e.g. wind direction differences due to local topographic features) but there is not a representative local dataset, the proponent may undertake an on-site wind monitoring programme. In this case data from the selected regional upper air stations must be obtained for the year in which the local monitoring takes place. Preparation of the representative dataset by the proponent should then proceed as described in the paragraph above.

8.1.3 Comparison of Wind Statistics

Annual statistics of local and regional wind speed and direction are to be compared. The comparison of seasonal statistics and night/day statistics can also be important when the significant variations between local and regional meteorological data are confined to certain periods. An example of this is the effect of lake breeze during spring and summer. For lakeshore locations local statistics for the 6 month period from mid-April to mid-October should be compared with the regional statistics on a 24 hour and night/day basis.

For the discussion that follows, the criteria for defining that local meteorology departs from regional values are such that this departure is larger than the year to year differences in the regional data. Statistics for the (Flint) regional data for 1983 have been compared by MOE with 30-year Flint data in developing the criteria.

Wind Speed

If the local mean wind speed is outside the range, regional mean wind speed $\pm 15\%$, then modification of the regional data is required.

The shape of the wind speed distribution is also important, particularly at the upper end of the wind speeds. In some cases the highest concentrations computed by the model occur with the highest wind speeds. Because comparison of extreme wind speeds can not be carried out with confidence, wind speeds which mark the division between the upper 10% and lower 90% of the wind speed data should be examined.

This can be done by establishing criteria either: (1) on the data itself or (2) on statistical distributions representing the best fit of the data.

- (1) If 10% of the regional wind speeds are above the value designated as V_R (Regional Winds) and 10% of the local wind speeds are above the value designated as V_L (Local Winds), then V_L should be within the range $V_R \pm 20\%$ or data modification is to be performed.
- (2) The hourly wind speed data in each of the regional and local datasets is to be fitted to a statistical distribution curve such as the Weibull, Chi-squared or Lognormal distribution. The curve parameters obtained for these distributions are then used to calculate for each population the wind speed which divides the upper 10% from the lower 90%. The criteria stated above in (1) are then applied.

Wind Direction

Wind direction is critical to the calculation of pollutant concentrations for which the regulatory standard is a 24 hour average or annual average value. For the 24 hour standard, knowledge of wind direction persistence during a 24 hour period is important. For the annual standard, wind direction frequency during the year is the significant factor.

The frequency and persistence of wind direction are to be calculated for 30 degree sectors, i.e., by first grouping the wind directions which are recorded in 10 degree intervals into sets of three: 10 to 30 degrees, 40 to 60 degrees, etc., twelve classifications in all.

Wind Direction Frequency

The frequency of wind direction from each of the 30 degree sectors is to be calculated from the hourly data for the year, or season. Comparison of local frequency statistics for the sectors with the 3 highest frequencies in the regional statistics will determine whether modification of regional data is required. If the frequency of any of the three most frequent regional wind sectors differs from the frequency in local dataset by more than $\pm 20\%$ then modification of the regional dataset is required.

Wind Direction Persistence

Wind direction persistence is defined here as the number of times that the wind direction occurs within a given wind sector for 10 hours or more in a 24 hour Julian day period. This is to be calculated for each sector. If the number of occurrences of persistent winds for all sectors combined differs from the regional dataset by more than ± 2 times the square root of the regional value, then modification of the regional dataset is required.

8.2 Procedures for Modifying the Regional Dataset

8.2.1 Lakeshore, Urban and Wind Channelling Locations

Lakeshore

For those hours when the lakeshore model is applicable, the internal boundary layer height is determined in the multisource dispersion module. This module uses information on the lake-land temperature contrast and on Z_i , the mixed layer height (determined from the regional upper air data) to derive the internal boundary layer height h as a function of downwind distance X (measured along the wind direction). The value of h is computed as:

$$h = A(X + X_o)^{1/2}, \quad (A.2.1.1)$$

$$\text{where } X_o = h_o^2/A^2.$$

Here h_o is the shoreline boundary layer height for the lake breeze hours (i.e., 50 m for non-urban settings and 100 m for urban settings).

For calculations other than in the Lakeshore model, the maximum boundary layer height is the smaller of Z_i or the value of h at $X = 15000$ meters.

The parameter A is calculated in the multisource dispersion as:

$$A = (u^*/um)[(T_L - T_w)\Gamma]^{1/2} \quad (A.2.1.2)$$

The values of the mixed layer average wind speed u_m , over-land surface temperature T_L and lake surface temperature T_w , are input values to the meteorological module. The friction velocity u^* is determined in the meteorological module. The vertical temperature gradient Γ is set to $0.03^\circ\text{C m}^{-1}$ if local observations are not available. If acoustic radar data are available these may be used in an alternative calculation of the height of the internal boundary layer. For an acoustic radar boundary layer height h_R at a distance X_R from the shoreline,

$$A = h_R / (X_R + h_R^2 / A^2)^{1/2} \quad (\text{A.2.1.3})$$

which can be solved iteratively for A .

Lake temperature values are monthly average surface temperatures over deep water, based on either satellite data or spot measurements of water surface temperature.

Lake surface temperature data available from AES are presented in two forms: (i) maps with isolines of surface temperature and (ii) digital gridded data on tape or diskette. Because this is satellite data for clear days only, the dates for which the data are available are irregular. Routine information is limited to the Great Lakes including Lake St. Clair, but Lake Simcoe is sometimes included. Monthly average surface temperatures away from the shoreline can be used.

Because the lake breeze effect in spring and summer may influence local wind patterns, the local dataset should be examined on a monthly, night/day basis to determine whether the criteria given in Section 8.1.1.3 for wind speed and direction are exceeded. If so, the procedure for data modification given below in Section 8.2.2 is to be followed.

Urban

For an urban location the minimum boundary layer height is to be set at 100 m. If comparison of local and regional wind data shows that the criteria in Section 8.1.3 are exceeded, the procedure for data modification given below in Section 8.2.2 is to be followed.

Valley Wind Channeling

If comparison of local and regional wind data shows that the criteria in Section 8.1.3 are exceeded, the procedure for data modification given below in Section 8.2.2 is to be followed.

8.2.2 All Locations

Wind Speed and Direction

When the statistical criteria in Section 8.1.3 are exceeded for either wind speed or wind direction, then the regional dataset is to be modified by replacing, hour by hour, both wind speed and direction with hourly values from the local dataset.

Where there are gaps in the local data, the regional data is to be retained. At some towers, winds are measured at several vertical levels above the 10 m surface level. When there is a higher level wind available at a tower, this should also be incorporated into the meteorological dataset. If several higher levels of winds are available at a tower the level used should be the level closest to the stack heights under consideration.

Snow on the Ground

Consideration should be given to local modification of the regional data for snow on the ground. Urban areas will have fewer hours with significant snow cover than non-urban areas. Sites which are in snow belt areas will have a greater number of hours with significant snow cover than will other locations.

A local dataset that has representative snow cover for the site can be used to replace, hour by hour, the snow cover data in the regional data.

Snow cover data can also be deduced by considering a combination of information including: NOAA daily weather maps giving a 1 inch and a 6 inch snow line, the local temperature and cloud cover and the observed local precipitation (i.e., snow or rain and when it occurred). The regional snow cover data is then to be modified, hour by hour, with snow values that reflect local conditions.

Table 8.1**Wind Measurement Stations of the Ontario Ministry of the Environment**

24 hourly observations/day

directions in ten degree intervals

All stations automatic; possible gaps in data

Station Name	ID	Year Began	Levels (metres)
WINDSOR-WRIGHT	12007	1984	10, 40
MERLIN	13021	1977	10, 9
COURTWRIGHT-HWY40	14016	1969	10, 30, 91
PARKHILL	15013	1983	10
LONDON-VICTORIA HOSPITAL	15018	1987	10
BEACHVILLE	17006	1974	10
TIVERTON-BRUCE	18013	1981	10, 30, 100
JARVIS	22883	1984	10, 85
LONGPOINT	22901	1979	10, 85
ALLANBURG	27011	1975	10, 37
HAMILTON-WOODWARD	29026	1975	10, 30, 90
TORONTO-LARCHMOUNT	31045	1974	21
TORONTO-JUNCTION	31120	1981	18
SCARBORO-LAWRENCE	33003	1970	12, 76
ETOBICOKE-EVANS	35033	1967	10, 30, 91
OSHAWA-RITSON	45025	1979	10
STOUFFVILLE	48002	1974	10
KINGSTON-MOBILE	52050	1988	?
CORNWALL-861 W 2ND	56065	1976	9
CORNWALL-MONTREAL RD	56100	1988	?
DRYDEN	61027	1984	12
FRANCES-COLONIZ'N	62032	1976	12
MARATHON-PENINSULA	63034	1982	12
RED ROCK	63084	1981	12
TERRACE BAY	63090	1981	12
SCHREIBER	63402	1988	-
ELLIOT LAKE	71060	1983	30
S.S. MARIE-WM. S	71068	1987	10
HOYLE/TIMMINS	72089	1987	10
NORTH BAY	75010	1979	10
HANMER	77013	1973	10
SUDBURY-FROOD	77025	1975	10, 116

TABLE 8.2

Wind Measurement Stations of the Atmospheric Environment Service

24 hourly observations/day
directions in ten degree intervals
Observation Level: 10 metres

Station	Start Month/Year	End Month/Year
ARMSTRONG*	09/1977	
BIG TROUT LAKE	05/1977	
CARIBOU ISLAND*	12/1979	
COBOURG*	06/1972	
COVE ISLAND*	07/1985	
ERIEAU/RONDEAU*	10/1985	
FORT FRANCES A	08/1976	
GERALDTON A	08/1981	
GODERICH*	11/1980	
GORE BAY A	10/1963	
GRAND BEND	10/1986	
GREAT DUCK IS.	01/1985	
HAMILTON A	08/1971	
KENORA A	08/1938	
KILLARNEY*	06/1985	
KINGSTON A	05/1978	
LANDSLOWNE HOUSE	09/1980	
MITCHELL'S BAY	10/1986	
MOUNT FOREST	10/1976	10/1986
MOUNT FOREST*	10/1986	
MUSKOKA A	12/1938	04/1980
NIAGARA FALLS GRASS IS.	01/1633	
NORTH BAY A	07/1939	
OLIPHANT	10/1986	
OTTAWA INT'L	10/1938	
PEAWANUCK*	09/1987	
PETAWAWA A	03/1972	
PETERBOROUGH A	07/1973	03/1986
PICKLE LAKE	11/1974	
POINT PETRE*	05/1975	
PORT COLBORNE*	10/1985	
PORT WELLER*	07/1975	
RED LAKE A	09/1977	

Table 8.2 continued...

Station	Start Month/Year	End Month/Year
ST CATHARINES A	07/1973	06/1982
SARNIA A	08/1973	
SAULT STE. MARIE A	12/1971	
SIMCOE*	11/1982	
SIOUX LOOKOUT A	07/1941	
SOUTHEAST SHOAL*	11/1985	
SUDBURY A	02/1954	
THUNDER BAY A	08/1941	
TIMMINS A	04/1955	
TORONTO DOWNSVIEW A	05/1977	
TORONTO HEADLAND*	05/1980	
TORONTO ISLAND A	01/1973	
TORONTO PEARSON/INT'L A	11/1937	
TRENTON A	07/1944	
UPSALA*	10/1970	
WATERLOO WELLINGTON A	08/1973	04/1986
WAWA A	10/1976	
WESTERN ISLAND*	04/1984	
WIARTON A	07/1947	
WINDSOR A	07/1940	
WINISK A	09/1981	

*Automatic observations; possible gaps in data

APPENDIX 8-4

A USER'S GUIDE TO THE AIR QUALITY MODELLING SOFTWARE

CAVEAT

These models are as described in the Clean Air Program Document Appendix 8-2

The models and documentation are subject to revision based on the comments received during the public discussion period.

TABLE OF CONTENTS

1 Introduction	1
2 Installation	2
2.1 System Requirements	2
2.2 Performing the Installation	2
3 Worst Case Meteorology Program (WCM)	5
3.1 Changes from the Previous Version	5
3.2 Executing the Program	5
3.3 Inputting the Source Data Interactively	6
3.4 Optional Source Inputs and Meteorological Restrictions	
3.5 Meteorological Resolutions	11
3.6 A Sample WCM Run	11
4 Meteorological Program (METM)	12
4.1 Changes from the Previous Version	12
4.2 Executing the Program	12
4.3 A Sample METM Run	14
5 Multiple Source Gas Dispersion Program (GAS)	15
5.1 Changes from Previous Version	15
5.2 Executing the Program	15
5.3 Creating a Run File	16
6 Shoreline Program (SHLINE)	21
6.1 Changes from Previous Version	21
6.2 Executing the Program	21
6.3 A Sample Run	23

APPENDIX A: File Management Facility Program (FM)	24
A.1 Executing the Program	24
A.2 Fundamental Concepts	24
A.3 Browsing Through a File	26
A.4 Modifying or Creating a file	27
APPENDIX B: Meteorological File Conversion Program (METCO)	32
APPENDIX C: Receptor File Generation Program (RECGEN)	34
C.1 Executing the Program	34
C.2 Receptor Layout	34
C.3 Receptor Spacing and Heights	35
C.4 Modifying the Output File	35
C.5 A Sample RECGEN Run	35
APPENDIX D: Record Layouts	37
APPENDIX E: Routine Calling Structures	48
APPENDIX F: Common Blocks	52
APPENDIX G: Porting and Recompiling the Source Code	57
APPENDIX H: Troubleshooting Guide	58

1 Introduction

The Ontario Ministry of the Environment (MOE) has developed a set of computer programs for the Clean Air Program (CAP) small-scale air quality models. These programs allow you to perform two basic tasks. (i) They allow you to compute the concentration due to emissions at a given set of receptors for a given set of meteorological and source parameters. (ii) They allow you to compute the meteorological conditions that produce the highest concentration for a given source.

This user's guide covers the installation and use of the programs, and assumes that you are familiar with the most basic concepts and terminology relating to air quality source assessment. It is recommended that you look over the Clean Air Program Document Appendix 8, Subappendix 2 (part 2) entitled "Detailed description of the multi-source air quality modelling technique for calculations of local air concentrations", which describes many of the concepts, terminology and equations involved in these programs. An overview of how modelling should be performed when seeking a Certificate of Approval is described in the Clean Air Program Document Appendix 8, Subappendix 1 (part 1) entitled "A General User's Guide to Source Assessment".

The programs *must* be installed prior to use. For installation instructions, see section 2. If you wish to run only the Worst Case Meteorology Program (WCM), refer first to section 2 and then to section 3.

A number of additions and modifications have been made to the functionality of the computer programs since the previous release (June, 1988 for the meteorological and multisource gas programs and December, 1988 for the worst-case meteorology program). Please refer to the appropriate sections (at the beginnings of the chapters) for a general description of these changes. It should be noted that all file formats have changes except met input (.min), receptor (.rec), annual average (.avg), julian day maximum (.jdm), and percentage contribution (.per).

Prior to proceeding, please refer to the file READ.ME on diskette #1 for any changes subsequent to the writing of this user's guide. To read this file, place diskette #1 in drive A of a PC or compatible and type:

TYPE A:READ.ME

and press <Enter>. You may stop the screen from scrolling by typing <Cntl> S. The scrolling can be restarted by typing <Cntl> Q. Please refer to the TYPE command in your DOS manual for more information. To use the <Cntl> key, hold it down and press the other key.

2 Installation

The programs *must* be installed prior to use. The installation package consists of 3 double-density double-sided (DSDD) 360 Kbyte 5.25" diskettes. If your computer can only use 3.5" diskettes, arrangements can be made to supply the programs in this format. In order to conserve space, most of the files on the diskettes are archived using a public domain program. When de-archived, the files will expand in size substantially.

2.1 System Requirements

The following minimum hardware and software is required in order to install and run the programs in this package.

- IBM PC/XT/AT or compatible
- 512 Kbytes of random access memory (RAM)
- colour or monochrome display and adaptor
- two DSDD (360 Kbyte) 5.25" floppy disk drives
- DOS 2.0 or greater

It is also recommended (though not required) that your system have a hard disk drive and an 8087 (80287 for AT) math co-processor.

During the installation, you will be asked whether or not your computer has an 8087 (80287 for AT) math co-processor. You should find out whether or not you have a co-processor before you perform the installation. If you are not sure, perform the installation as if you do have one. The program GAS comes in two versions: One works fastest with a co-processor and one works fastest without. Only one of the two will be installed. Note that other than the question of speed, both versions are identical in usage and results.

If you wish to install the programs on a computer that is not PC compatible, or if you wish to modify or re-compile the programs, please refer to appendix G.

2.2 Performing the Installation

(a) Creating a Working Copy of the Diskettes

You should make copies of the supplied diskettes and use the copies for installation. Keep the originals in a safe place. The diskettes can be copied by typing the DOS command:

DISKCOPY A: B:

and inserting the diskette to copy in drive A and a blank diskette in drive B. Repeat this process for all the diskettes. It is recommended that you cover the write-protect tabs on the diskettes after the copying procedure. NOTE: It is not possible to use a high density (1.2 Mbyte) diskette in a low density (360 Kbyte) diskette drive. But it *is* possible to use a low density diskette in a high density drive.

(b) Installing on a Floppy Disk Based System

Prior to installing the programs, prepare 3 formatted DSDD (360 Kbyte) floppy diskettes. If the diskettes are not formatted, place the blank diskettes in drive B and type the DOS command:

FORMAT B:

IMPORTANT: Formatting a diskette destroys any data residing on it.

To perform the installation, insert diskette #1 in drive A and type:

A:\INSTALLF

then follow the directions as they appear on the screen. After the installation, diskette #1 will contain GAS. Diskette #2 will contain METM, SHORE and WCM and its associated configuration file. Diskette #3 will contain METCO, RECGEN, the sample files, and FM and its associated files. If an error is made during installation, delete all the files on the target diskette and repeat the installation. Please be sure that your CONFIG.SYS file is properly set up (see step 2.2(h)).

(c) Executing Floppy Disk Based Programs

In order to run a particular program, it is recommended that you place the diskette containing the program in drive A. Then place the diskette containing the input files in drive B. Direct any output produced by the program to drive B. While executing a program from drive A, you may refer to files on drive B by prefacing the filename with 'B:'.

(d) Installing on a Hard Disk Based System

To perform the installation, insert diskette #1 in drive A and type:

A:\INSTALLH

then follow the instructions as they appear on the screen. The programs will be placed in directory C:\CAP. FM's associated files will be placed in C:\CAP\FMUTIL. The sample files will be placed in C:\CAP\SAMPLE. All three directories will be created automatically during the installation process. NOTE: You will need approximately 1 megabyte (1000 Kbytes) of free space on the C drive of your hard disk for the installation. Be alert for an "Insufficient disk space" error during installation. If an error is made during installation, delete all the files and directories in C:\CAP and repeat the installation. Please be sure that your CONFIG.SYS file is properly set up (see step 2.2(h)).

(e) Executing Hard Disk Based Programs

In order to run a particular program, use the DOS CD command to go to directory C:\CAP (i.e. type C: and CD \CAP) and type the CAP program name, CAP. Alternatively, you may

execute the program by name (METM, WCM, etc.) from any directory, provided that the PATH refers to C:\CAP. Refer to your DOS manual for a description of pathnames, directories, and the CD and PATH commands.

It is recommended that you place your various input and output files in separate directories, for the sake of organization. Then refer to the files by using absolute or relative pathnames.

(f) Installing on a Local Area Network (LAN)

Perform the installation as in step 2.2(d), above, for installing on the C drive of a hard disk. The installation cannot be performed if the station (terminal) being used is not connected to a C drive.

(g) Executing Local Area Network (LAN) Based Programs

Execute the programs as in step 2.2(e), above, for executing hard disk based programs. NOTE: The program FM assumes that its associated files will be resident on the C drive. If your station (terminal) does not view the CAP programs as residing on the C drive, you will not be able to execute FM. In a similar vein, if a run file (see section 5) is created with absolute pathnames referencing the C drive, the same run file cannot be used from a station connected to that drive but viewing it as, say, an F drive.

(h) Modifying the CONFIG.SYS File

In order that the CAP programs can open all their files, and in order to run program WCM's screen graphics, your machine must be initialized properly. The CONFIG.SYS file *must* have the statements

DEVICE=ANSI.SYS and FILES=25 (or greater) added to it. You will find the CONFIG.SYS file in the root directory (i.e. C:\CONFIG.SYS for hard disk based systems or A:\CONFIG.SYS for floppy diskette based systems). If your system has no CONFIG.SYS file, create one and insert the 2 lines specified above. You may use your DOS editor EDLIN to create or modify the CONFIG.SYS file. Please insure that the file ANSI.SYS (found on your original DOS diskettes) is in the same directory as the file CONFIG.SYS (i.e. in the root).

In order to speed up I/O, you may also wish to insert a BUFFERS command (e.g. BUFFERS=20) in the CONFIG.SYS file. Program execution can be further speeded up (at some cost to flexibility) by omitting the BREAK command. Please refer to your DOS manual for information on the CONFIG.SYS and ANSI.SYS files, the EDLIN editor, and on the DEVICE, FILES, BUFFERS and BREAK commands.

Once the CONFIG.SYS file has been changed, re-boot the machine.

3 Worst Case Meteorology Program (WCM)

The CAP worst case meteorology program is designed to allow you to compute the meteorological conditions that produce the highest concentration for a given source. The input consists of source and site data such as stack height and surface roughness and the output consists of meteorological parameters such as wind speed and friction velocity.

3.1 Changes from the Previous Version

Some additions and modifications to the functionality of WCM have occurred since the December, 1988 version. These changes include the capacity for specifying:

- an initial total vertical or horizontal plume size
- an inputted (user-computed) momentum flux
- the site setting as either urban or a rural
- a fixed value for the wind speed
- a fixed value for the convective boundary layer height
- an above-ground receptor
- an emission rate other than 1.0 grams/second

One of the stack parameter units has changed. The stack *radius*, rather than the diameter, is now required when inputting interactively. The format of the input and output files has changed.

3.2 Executing the Program

To execute WCM from a floppy diskette, place the floppy diskette containing WCM in drive A and type:

```
A:\WCM
```

If you have any input or output files to specify, place a floppy diskette in drive B and use that diskette for the files. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute WCM from a hard disk, type:

```
C:                and:  
CD \CAP
```

then invoke the CAP program by typing:

```
CAP
```

and choose option 1.

(a) Selecting a Source of Input Data

You may enter input data from either the keyboard or a (previously prepared) file. The output can be directed to either the screen or an output file.

When you execute WCM, you will first be asked:

Do you wish the input data read from the KEYBOARD or a FILE? [K] >

If you reply by pressing 'K', or just <Enter>, then you will be prompted for the input data interactively.

If you reply by pressing 'F' then you are indicating that you wish to input from a file. In this case, WCM will prompt you for a filename. This file must exist for the program to execute correctly. To create this input file, use the program FM (see appendix A) and the record layout for a WCM input file (appendix D) or use your own editor in conjunction with the record layout for a WCM input file (appendix D). If there is more than one source in this input file, then the sources will be processed individually and sequentially. In other words, WCM performs a single source worst case run, not a full multisource worst case run.

(b) Selecting a Target for Output Data

After being asked for a source of input data you will be asked

Do you wish the output data written to the SCREEN or a FILE? [S] >

If you reply by pressing 'S' or just <Enter> then the output will appear on the screen. If you reply by pressing 'F' then you are indicating that you wish to direct the output to a file. In this case, WCM will prompt you for a filename. NOTE: The file will be created if it does not exist and will be overwritten if it does exist. If you wish a hardcopy (printout) of the file, use the DOS PRINT command. The output file will be 132 columns wide, so place your printer in compress mode if you will be printing on an 80 column printer. (Please refer to your printer manual for instructions on compressing text.)

NOTE: If during interactive input you have not specified an emission rate, an emission rate of 1 gram/second is assumed. You may later simply scale up (or down) the outputted concentrations by multiplying them by the actual emission rate (in units of grams/second). In other words, the concentration is directly proportional to the emission rate.

3.3 Inputting the Source Data Interactively

When entering input data by keyboard, simply pressing <Enter> is identical to entering 0. The lone exceptions to this are the downwind search distances. The default for the nearest receptor is 10 meters. The default for the farthest receptor is 25000 meters.

You will be asked for various parameters by WCM. These include: the stack height, radius, temperature, exit velocity, and a building height and width (if any). In addition, you will be asked for the nearest receptor, the farthest receptor, the surface roughness, and an

indication as to whether the setting is urban or rural.

(a) Inputting the Stack Temperature

The stack temperature is entered in degrees celcius. WCM assumes a 2 meter air temperature of 20 degrees celcius. If you wish to enter an ambient stack temperature, enter a stack temperature of -999 degrees celcius. This temperature is clearly impossible. It is a code that indicates that WCM should use the ambient temperature for a stack temperature.

(b) Inputting a Calculated Buoyancy Flux

If you wish to enter your own calculated buoyancy flux (in, for example, a flare situation) rather than have WCM calculate one, enter a stack temperature of -888 degrees celcius. This temperature is clearly impossible. It is a code that indicates that you would like to enter your own buoyancy flux. WCM will then later on ask you for a buoyancy flux.

If, having entered a code of -888, you later decide that you want WCM to compute the buoyancy flux, simply change the stack temperature to the new value (when later given the opportunity to do so, prior to the dispersion calculations) and the inputted buoyancy flux will be cancelled.

(c) Inputting a Calculated Momentum Flux

If you wish to enter your own calculated momentum flux rather than have WCM calculate one, enter a stack exit velocity of -888 meters/second. This exit velocity is clearly impossible. It is a code that indicates that you would like to enter your own momentum flux. WCM will then later on ask you for a momentum flux.

If, having entered a code of -888, you later decide that you want WCM to compute the momentum flux, simply change the stack exit velocity to the new value (when later given the opportunity to do so, prior to the dispersion calculations) and the inputted momentum flux will be cancelled.

(d) Inputting an Initial Total Vertical Plume Height

If you wish to enter an initial total vertical plume height, enter a building height of -888 meters. This building height is clearly impossible. It is a code that indicates that you would like to enter an initial total vertical plume height. WCM will then later on ask you for an initial total vertical height (in meters).

If, having entered a code of -888, you later decide that you want no inputted initial total vertical plume height (or you wish to enter a positive building height), simply change the building height to 0 (meaning no building height or initial total vertical plume height) or a new value of the building height (when later given the opportunity to do so, prior to the dispersion calculations). The inputted initial total vertical plume height will then be cancelled.

It is not possible to enter both a positive building height and an initial total vertical plume height.

(e) Inputting an Initial Total Horizontal Plume Width

If you wish to enter an initial total horizontal plume width, enter a building width of -888 meters. This building width is clearly impossible. It is a code that indicates that you would like to enter an initial total horizontal plume width. WCM will then later on ask you for an initial total horizontal plume width (in meters).

If, having entered a code of -888, you later decide that you want no inputted initial total horizontal plume width (or you wish to enter a positive building width), simply change the building width to 0 (for no building width or initial total horizontal plume width) or a new value of the building width (when later given the opportunity to do so, prior to the dispersion calculations). The inputted initial total horizontal plume width will then be cancelled.

It is not possible to enter both a positive building width and an initial total horizontal plume width.

(f) Entering the Nearest and Farthest Receptors

The nearest receptor is normally the distance from the source to the property line or nearest critical receptor. It cannot fall below 10 meters. The farthest receptor should not normally exceed 25000 meters, as the dispersion calculations may then become meaningless. If you wish to compute the worst case concentration at one particular receptor, set both the nearest and the farthest receptor to that same distance. In convective cases, the minimum receptor allowed may sometimes exceed 10 meters. In these cases, WCM will adjust your inputted minimum receptor distance upwards if it is too small.

(g) Inputting a Surface Roughness

The surface roughness is inputted in centimetres (during interactive input), not meters as in the input file or in the meteorological module (see section 4). A table of possible surface roughness figures is reproduced below. (Reference: Pasquill [1974] and Seinfeld [1975])

Surface	Roughness Length (cm)
-----	-----
Very Smooth (ice, mud flats)	0.001
Snow	0.005
Smooth Sea	0.02
Lawn, grass up to 1 cm high	0.03
Lawn, grass up to 5 cm high	1-2
Lawn, grass up to 50 cm high	4-9
Fully grown root crops	14
Forest	100
Urban Core	100

(h) Correcting Inputted Stack Parameters

If you make a mistake in entering a stack parameter, there will be an opportunity for you to correct it before WCM uses the parameters to perform dispersion calculations. After all the parameters have been entered, you will be prompted for any correction by being asked:

Would you care to alter any of the values? (Y/N) [N] >

If you press 'N' or just <Enter> then WCM will proceed with its dispersion calculations. If you press 'Y' then you will be prompted for the number of the parameter to change by being asked:

Which value do you wish to modify? (1-18) ==>

Enter the number of the parameter and re-enter the correct value for the parameter when asked to do so. WCM will then re-display the final screen and again prompt you for any corrections. NOTE: If you have entered, say, a buoyancy flux and then decide you wish to have WCM calculate the flux, simply change the relevant parameter, in this example the stack temperature, from the code -888 to the correct value.

(i) Running Another Interactively Inputted Source

After having viewed on screen the output of an interactive session, you will have 3 options. You may type "Q" to quit WCM. You may type <Enter> and reenter another source's characteristics for another run. Or you may type "N" to modify the current source's characteristics for another run. This last option can be particularly useful if you wish to process a couple of very similar sources.

(j) Summary of Special Codes for Input Parameters

Original Parameter	Code	Result
--------------------	------	--------

Stack Temperature	-999	Ambient Stack Temperature
"	-888	Ask for Buoyancy Flux
Exit Velocity	-888	Ask for Momentum Flux
Building Height	-888	Ask for Initial Total Vertical Plume Height
Building Width	-888	Ask for Initial Total Horizontal Plume Width

3.4 Optional Source Inputs and Meteorological Restrictions

In addition to the standard source inputs described in section 3.3, such as stack height and buoyancy flux, WCM allows for the input of 2 other source characteristics: Emission rate

and receptor height above ground. The user may also direct WCM to only consider a particular inputted value of the convective boundary layer height or a particular inputted wind speed. These 4 inputs are normally not asked for, but this can be changed by modifying the WCM.CFG configuration file. NOTE: These optional inputs are only available if the source data is being inputted interactively.

(a) Optional Source Inputs

Normally, the emission rate is assumed to be 1.0 grams/second. Any final concentration can then simply be scaled up by the true emission rate, as described in section 3.2(b). But WCM can be directed to ask the user for an actual emission rate.

Normally, the receptor height is assumed to be 0 meters. In other words, WCM normally assumes the receptor to be at ground level. WCM can be directed to ask the user for a receptor height above ground. This can be useful in computing, for example, the worst case concentration at the 10th floor of an apartment building.

(b) Optional Meteorological Restrictions

Normally, WCM searches through all reasonable wind speeds in order to find the one that produces the worst concentration. This automatic search can be overridden if the user has a particular wind speed in mind. All computations will then take place with that wind speed.

Normally, WCM searches through all reasonable convective boundary layer heights to find the one that produces the worst concentration under convective conditions. This automatic search can be overridden if the user has a particular convective boundary layer height in mind. All convective computations will then take place with that boundary layer height.

If either of these two meteorological restrictions are put in place, the output of WCM can be considered to be the worst case qualified by the additional restriction(s). NOTE: These optional meteorological parameters must fall within their respective reasonable ranges. If they do not, WCM will automatically change them to the nearest reasonable value.

(c) Modifying the WCM.CFG Configuration File

In order to input the parameters discussed above, the WCM.CFG configuration file must be modified. If WCM cannot find WCM.CFG, it will continue execution without asking the user for the optional inputs. This implies that if the user does not want to be asked for the optional inputs, no WCM.CFG file need exist.

WCM searches for WCM.CFG in first, the current directory. If it is not found then it searches the directory C:\CAP. If it is not found there (or if the computer has no C drive) then it searches the directory A:\. Finally, it searches the directory B:\.

In modifying WCM.CFG, you may use program FM (see appendix A) or your own editor in conjunction with the WCM.CFG record layout as described in appendix D. In summary,

there are 4 fields in WCM.CFG, one for each parameter. Setting the field to F implies that you do not want to be asked for the parameter, and setting the field to T means that you *do* want to be asked for the parameter.

A sample WCM.CFG file might look like this:

FFTF

meaning that the user wishes to be asked the emission rate, since the third field is T. No other optional parameters will be asked for, since all other fields are F.

3.5 Meteorological Resolutions

Some of the outputted meteorological results are resolved to within certain tolerances. The wind speed is resolved to the nearest 0.25 of a meter per second. The downwind distance in elevated cases is resolved to the nearest 10 meters. The downwind distance in near surface cases is resolved precisely. The convective boundary layer height is resolved to the nearest 10 meters. The convective velocity scale is resolved to the nearest 0.25 of a meter per second.

3.6 A Sample WCM Run

A sample WCM input file might look like this:

```
60.00 -999.0 1.2000 5.000 10.00 20.00 10.0025000.00 0.2000 0.000 0.000 0.00 0.00U
```

In this case, the stack height is 60 meters, the stack temperature is -999 celcius (i.e. ambient), the stack radius is 1.2 meters, the exit velocity is 5 meters/second, the building is 10 meters high and 20 meters wide, the surface roughness is 0.2 meters (i.e. 20 centimetres) and the setting is urban. Because none of the stack temperature, exit velocity or building dimensions are -888, the inputted buoyancy flux, momentum flux and initial total vertical and horizontal plume sizes (the last 4 fields) are 0. A dialogue with WCM might then look like this (user replies are in boldface):

CAP Small-Scale Model: Worst Case Meteorology Program, July 1990 Version

Do you wish the input data read from the KEYBOARD or a FILE? [K] >F

Please enter the WORST CASE INPUT (.wci) filename [] >WCMTEST.WCI

Do you wish the output data written to the SCREEN or a FILE? [S] >F

Please enter the WORST CASE OUTPUT (.wco) filename [] >WCMTEST.WCO

4 Meteorological Program (METM)

The CAP meteorological program is designed to allow you to calculate meteorological parameters such as Monin-Obukhov Length and friction velocity on the basis of standard meteorological input supplied by you, such as wind speed and surface roughness.

The resulting output file is used as input to the multisource dispersion model GAS (see section 5).

4.1 Changes from the Previous Version

Some additions and modifications to the functionality of METM have occurred since the December, 1988 version. These changes include the capacity for specifying:

- the setting as either urban or rural
- the amount of wind direction randomization (if any)

In addition, the program name has been changed from MET.

4.2 Executing the Program

To execute METM from a floppy diskette, place the floppy diskette containing METM in drive A and type:

```
A:\METM
```

Use drive B for your input and output files. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute METM from a hard disk, type:

```
C:          and:  
  CD \CAP
```

then invoke the CAP program by typing:

```
CAP
```

and choose option 2.

You will then be prompted for 7 pieces of information: a met input filename, a met output filename, a latitude, a longitude, a surface roughness, whether the setting is rural or urban, and the amount of wind direction randomization.

(a) Met Input File

This file must exist prior to program execution. It contains such data as the day of the year, the wind speed, and the amount of cloud cover. It must end in a '.min' extension. It can be prepared or modified using FM (see appendix A). If you use your own file of analyzed met input data, please insure that it has the correct record layout (see appendix D).

(b) Met Output File

This file must end in a '.met' extension. It need not exist prior to program execution. If it does not, it will be created automatically. If it does exist, you will be given the option of overwriting the file or stopping the program. If you wish, the met output file can be modified or prepared (from given values) using FM (see appendix A).

(c) Latitude of Site

You should enter the latitude of the site in decimal degrees. For example, a latitude of 45 degrees and 15 minutes equals 45.25 degrees.

(d) Longitude of Site

You should enter the longitude of the site in decimal degrees. For example, a longitude of 80 degrees and 30 minutes equals 80.5 degrees.

(e) Surface Roughness of Site

Enter the surface roughness in meters. A table of empirical surface roughness values can be found in section 3.3(g). The surface roughness must be greater than 0 meters.

(f) Amount of Wind Direction Randomization

When running METM, you will be asked:

Would you like wind direction randomization? (Y/N) [N] >

You should reply by pressing 'N' or <Enter> if you want the wind directions specified in the input file to be used exactly as they are. In some cases wind directions are rounded off, typically to every 10th degree. This situation can present problems in, say, computing annual averages. This is so because, in reality, the wind blows in every direction of the compass. Treating the wind as if it only blows every 10 degrees, or in only 36 directions, can skew a grid of concentrations into a 36-pointed star over a long range average. As a result, it might be necessary to randomize the wind direction to the same degree to which it was rounded off. In this case, reply to the above question by pressing 'Y'. You will then be asked:

Arc wind directions rounded off to every 10 degrees? (Y/N) [Y] >

If you answer with a 'Y' or <Enter>, the wind directions will be randomized by having

from -4 to +5 degrees added to them randomly. If you answer with a 'N', you will be asked:

How many degrees are wind directions rounded off to? [] >

The number that you enter should be positive and divisible evenly into 360 degrees. Note that the random number generator in the program has a hard-coded seed.

(g) Rural/Urban Site Flag

The site will be urban by default, unless rural is specified. This input affects minimum allowable values of convective and stable boundary layer heights.

4.3 A Sample METM Run

A Sample METM input file, METTEST.MIN, might look like this:

```
90052116      -1.000 170.2700000E+030.2300000E+01  2  0 230  0
```

In this case, the date is May 21, 1990 and the time is 1600 GMT (1100 EST). There is no alternate wind speed (it equals -1.0). The 2 meter air temperature is 17 degrees celsius, the wind direction is 270 degrees azimuth, and the 10 meter wind speed is 2.3 meters/second. The cloud cover is 2 eighths, there is no snow cover (0), the convective mixed layer height is 230 meters, and the met data flag is 0.

A dialogue with METM might then look like this (user replies are in boldface):

CAP Small-Scale Model: Meteorological Program, July 1990 Version

Please enter a MET INPUT (.min) filename [] >**METTEST.MIN**

Please enter a MET OUTPUT (.met) filename [] >**METTEST.MET**

Enter the latitude of the site in decimal degrees (eg. 44.50) [] >**46.2**

Enter the longitude of the site in decimal degrees (eg. 80.30) [] >**79.4**

Enter the surface roughness of the site in meters [] >**0.1**

Would you like wind direction randomization? (Y/N) [N] >**N**

Is this an Urban or Rural setting? (U/R) [U] >**U**

5 Multiple Source Gas Dispersion Program (GAS)

The CAP multisource gas dispersion program is used to calculate the concentration at receptors due to emissions produced by sources under given meteorological conditions. GAS can be run for either a single or multiple (maximum of 50) source situation. There can be as few as 1 or as many as 1000 receptors, and as many met cases as you wish. GAS allows you to easily find the maximum straight downwind concentration for a single source. It also allows you the option of generating some basic statistics, such as the maximum hourly concentration and the maximum 24 hour average concentration.

NOTE: An invalid meteorological record (IFLAG = 800 or 999) will produce negative concentrations as a flag value. In the event of averaged output, the concentration will be negative if too many of the individual concentrations that went into the average were negative.

5.1 Changes from Previous Version

Some additions and modifications to the functionality of GAS have occurred since the release of the June, 1988 version. These changes include the capacity for specifying:

- from 2 to hour moving average maximum concentration output
- a geometric mean of concentration output
- a nearby shoreline for use in shoreline calculations
- lake temperatures for use in shoreline calculations
- hourly stack temperatures, exit velocities and emission rates
- an output dump file of all concentrations computed
- a user computed momentum flux for a source
- an initial total vertical and horizontal plume size for a source
- building dimensions for a source in greater detail
- a coarse and fine grid search
- special receptors input
- a receptor height for straight downwind calculations

In addition, some further changes were made, among them:

- wind direction randomization was moved to the meteorological program (see section 4)
- the area source input was replaced by initial total vertical and horizontal plume sizes

5.2 Executing the Program

To execute GAS from a floppy diskette, place the floppy diskette containing GAS in drive A and type:

```
A:\GAS
```

Use drive B for your input and output files. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute GAS from a hard disk, type:

```
C:          and  
CD \CAP
```

then invoke the CAP program by typing:

```
CAP
```

and choose option 3.

5.3 Creating a RUN File

When you invoke GAS, you will immediately be prompted for a RUN filename. This filename must end in a '.run' extension. The RUN file contains a list of the files that will be used as input and output to GAS. It is therefore very easy to keep track of individual runs. Simply type out the RUN file used for the run, and you will have a list of the files that you used.

If the run file that you entered exists, then all the input files that it specifies will be checked. If these input files (e.g. source, met, function) all exist, then GAS performs the dispersion calculations. If some of these input files do not exist, then GAS will tell you which ones do not exist and end. You must then create these missing files (using, for example, FM in appendix A) and re-run GAS with the same RUN file. The dispersion calculations will then be performed.

If the RUN file that you entered does not exist, then GAS will prompt you for files to include in it, and then attempt a dispersion calculation. This will, of course, be the case when you first run GAS.

(a) Summary File

For a new run, the first file you will be asked for is a SUMMARY file. This file can be made 'nul' by simply typing <Enter>. In this case, no summary file will be produced. If you do enter a summary filename, it must have the extension '.sum'. The summary file contains such data as echoed source and met information, and the concentration at each receptor. If you are running more than a couple of met cases with a few hundred receptors, the summary file will contain a large and indigestible amount of data. If many met cases are being processed, the summary file should be blanked out by pressing <Enter>. A general rule of thumb is that the number of lines in the summary file will equal the number of receptors times the number of met cases.

Please note that if you print a summary file, you should allow for 132 columns. To place an 80 column printer in compress mode, consult your printer manual.

(b) Detail File

The DETAIL file is the next filename you will be asked for. The detail file must end with a '.det' extension. It contains a detailed listing of intermediate calculations performed. It is used mostly for program debugging, but it may be useful to you for finding out such values as virtual source location. However, be warned: Except for a small, limited run, the detail file will be enormous. It could easily fill your entire (hard) disk and crash the program. Generating a detail file also considerably lengthens execution time. A general rule of thumb is that the number of lines in the detail file will equal $S \times R \times M \times 2$, where S is the number of sources, R is the number of receptors and M is the number of met cases. If you print a detail file, allow for 132 columns (place your printer in compress mode). You will almost always not want a detail file. In this case, simply press <Enter> when asked for a detail filename to 'dummy' it out.

(c) Source File

The third file you will be prompted for is a SOURCE file. It must end with extension '.src'. It contains such data as stack height and stack exit velocity. This is a required file for dispersion calculations. In other words, it cannot be 'NUL'. A source file can be created using FM (see appendix A). See appendix D for information on source record layouts.

(d) Meteorological File

The fourth file that GAS prompts you for is a METEOROLOGICAL file. It must end in a '.met' extension. It contains such data as wind speed and friction velocity. It is generated using METM (see section 4) or possibly with FM (appendix A). This is a required file for dispersion calculations, and therefore cannot be 'nul'.

(e) Function File

The fifth file you will be asked for is a FUNCTION file. It must end in a '.fun' extension. It tells GAS which function options you have chosen for the run. It contains such data as whether or not you wish to print the hourly maxima, and whether you wish a straight downwind maximum run. This file is required for dispersion calculations, and therefore cannot be 'NUL'.

The function file can be generated using FM (appendix A), however it need not be. If the function file does not exist, it will be easier if you allow GAS to create it and prompt you for data to fill it with.

You will first be asked whether or not this is a single source straight downwind maximum run.

(f) Straight Downwind Maximum Run

If this is a single source straight downwind run, you will next be prompted for a minimum X value. This should be between 10 and 25000 meters. It is the distance from which the downwind search will begin, and is typically the distance from the stack to the plant boundary or first critical receptor. Next, you will be asked for a maximum search distance.

The default value is 25000 meters. GAS will search for the maximum concentration between the minimum and maximum X distances. You will then be asked for a receptor height above ground at which to perform the calculations. This value is normally 0 for a ground-level maximum run.

Next, you will be asked for an HOURLY MAXIMUM filename. This filename must end in the extension '.hmx', but it can be 'NUL'. The hourly max file is an output file written to by GAS that contains a list of the maximum concentration over the receptors, and the receptor at which it occurred, for each met case used.

Finally you will be asked for 3 further input files, all of which are optional: The HOURLY EMISSIONS file, the HOURLY STACK TEMPERATURE file and the HOURLY STACK EXIT VELOCITY file. These options are useful if any of these 3 parameters change on an hourly basis. Consult FM (appendix A) and the source record layouts (appendix D) for information on generating these files.

After this, GAS generates the function file and performs the dispersion calculations. Note that a straight downwind max run is the only situation in which you need not supply a receptor file. Also, regardless of the (x,y) position given for the stack location, it is assumed to be at (0,0).

(g) Multiple Source or Non-Downwind Max Run

A straight downwind run cannot be performed for a multiple source situation. In such a case, use a receptor grid with an appropriate spacing.

In a non-downwind max run, you will first be asked for a RECEPTOR (.rec) file. This is an input file. It is required for a non-downwind run. You may generate a receptor file using RECGEN (appendix C) or FM (appendix A).

MOVING AVERAGE (.mov) filename. Output. Optional. You will be asked for the number of hours (2-24) over which to perform the moving average. It is computed by averaging the hourly grid concentrations over the number of specified hours, and moving the average forward one hour at a time. Only the maximum concentration over the averaged grid is outputted. The number of output records will equal the number of met cases - 23.

HOURLY MAXIMUM (.hmx) filename. Output. Optional. The hourly max file is an output file written to by GAS that contains a list of the maximum concentration over the receptors, and the receptor at which it occurred, for each met case used. This file (together with the OLD HOURLY MAX file) can also be used in a coarse/fine grid search. The number of output records will equal the number of met cases.

JULIAN DAY AVG MAX (.jdm) filename. Output. Optional. This file will contain 1 record for each 24 hour's worth of met data, describing the maximum concentration of the average grid over the day. The number of output records will equal the number of met cases divided by 24.

AVERAGE GRID (.avg) filename. Output. Optional. This file contains the average grid over all the valid met cases run. In other words, GAS keeps a running average of the concentration at each receptor. The number of output records will equal the number of receptors.

PERCENTAGE CONTRIBUTION (.per) filename. Output. Optional. This file contains 1 record for each receptor. Each record consists of the (X,Y,Z) co-ordinate of the receptor plus the concentration at that receptor, plus an additional field for each source, giving its contribution as a fraction of the concentration. For example, the first record in a 3 source situation may look like:

1000.00 0.00 0.00 0.123456E+01 0.2300.5500.220

meaning that the receptor is (1000, 0, 0), the concentration was 1.23 UG/M**3, the first source contributed 23% of the total, the second source contributed 55%, and the third contributed 22%. You can use this file to plot contours (using your own contouring package), and also to decide which source is the significant contributor at a particular receptor. Due to the volume of output, the percentage contribution file is only written to for the first met case in the run.

OLD HOURLY MAX (.hmx) filename. Input. Optional. This option is useful for performing a coarse and fine grid search. In order to use this option, perform a GAS run with a coarse receptor file (with a spacing interval of, say, every 500 meters.) During this run, ask for an HOURLY MAXIMUM output file. Then run GAS a second time, but use finer gridded receptors (with an interval of, say, every 10 meters). The east-to-west distance of this second receptor file should be twice the first receptor file's east-west grid interval. And the north-to-south distance of this second receptor file should be twice the first receptor file's north-south grid interval. During the second GAS run, ask for an HOURLY MAXIMUM output file, and input the first GAS run's HOURLY MAXIMUM output file as the second GAS run's OLD HOURLY MAX input file. The resulting HOURLY MAXIMUM file will contain the correct finely gridded results. This whole process can save much computer time over the alternative: Running GAS with very many closely spaced receptors.

HOURLY EMISSIONS filename, HOURLY STACK TEMPERATURE filename, HOURLY STACK EXIT VELOCITY filename. All input. All optional. These options are useful if any of these 3 parameters change on an hourly basis. Consult appendix A (FM) and appendix D (record layouts) for information on generating these files.

Receptor Grid Rotation. Input. This option is used, for example to have a square receptor grid conform to certain geographical features. If you wish this option, enter a non-zero number when asked the number of degrees that you wish the grid rotated. You will normally not want this feature.

BUILDING filename. Input. Optional. This file can be created using FM (appendix A) and the record layouts (appendix D) if you wish to define buildings. Please read the notes in

appendix D for creating a BUILDING file.

GEOMETRIC MEAN concentration filename. Output. Optional. This file contains the geometric mean grid over all the met cases run. Note that you cannot use this feature without also entering a non-zero background concentration.

DUMP filename. Output. Optional. This file contains all concentrations over all receptors. The format is outlined in the Record Layouts section (appendix D). Note that the file is non-printable, since it contains real numbers in IEEE 32 bit format. Note also that the file can be very large. Its size can be estimated as Number of Receptors X Number of Met Cases X 4 bytes. You will normally not want this feature.

Special Receptors Definition and filenames. Input and Output. Optional. Special receptors will always have all their concentrations outputted for each met case, regardless of the other output options chosen. You can define up to 10 special receptors. If you choose the special receptor option, you will be given the option of inputting the special receptors interactively or through a file. If you choose to input your special receptors through a file, you can create the file by referring to FM (appendix A) and the Record Layout section (appendix D). The special receptor output will be placed in the file you specify.

Shoreline Definition and filenames. Input and Output. Optional. Finally, you will be asked for shoreline information. You will first be asked whether there is a shoreline within 15 kilometres of any significant source. If so, you will be asked for a point on the shoreline along with the azimuth angle of the shoreline. This is used by GAS to define the location of the shoreline. Finally, you will be asked for a LAKE TEMPERATURE file. This file is required for shoreline runs, and can be prepared using FM (appendix A). Note that if you run out of lake temperatures (required for meteorological cases from April 15 to October 15), GAS will terminate on error. In this case, modify the '.lkt' file and try again. Note also that in order for the shoreline calculation to be performed at all, at least one source must be located **off** the shoreline. If no source is located off the shoreline, GAS may terminate on error. If one source is located on one side of the shoreline and another source is located on the other side, the results of a GAS run may be incorrect. GAS uses source locations to determine which side of the shoreline the water is on. If any of these problems arise, correct either the source file or the shoreline definition and re-run GAS.

When all the function information has been received, GAS writes it out to the function file that you named and performs the dispersion calculations.

(h) Correcting an Error in the Run File

If, after entering filenames and data to create a new run file, you find that you entered an incorrect filename (and GAS ends before the dispersion calculations), simply delete the run file you created (using the DOS DEL command) and start over. This will not delete any '.fun' files created during the run. If the run file is complete but incorrect, it may be corrected by using FM (appendix A) and the Record Layout section (appendix D).

6 Shoreline Program (SHLINE)

The CAP shoreline program is used to calculate the concentration at receptors due to emissions produced by a stack in a shoreline environment under given meteorological conditions. SHLINE is run for a single source at a time. If you wish to run more than one source at a time, use GAS (section 5).

6.1 Changes from Previous Version

Some additions and modifications to the functionality of SHLINE have occurred since the release of the June, 1988 version. These changes include:

- using receptor files as in GAS
- inputting the stack radius rather than the diameter
- a program name change from SHMAIN

6.2 Executing the Program

To execute SHLINE from a floppy diskette, place the floppy diskette containing SHLINE in drive A and type

```
A:\SHLINE
```

Use drive B for your input and output files. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute SHLINE from a hard disk, type:

```
C:          and  
CD \CAP
```

then invoke the CAP program by typing:

```
CAP
```

and choose option 4.

You will then be prompted for a receptor filename, an output filename, and a variety of source and meteorological inputs.

(a) Coordinate System

The shoreline is assumed to be located at point (0,0) and is assumed to run north/south. In other words, the Y axis is assumed to be the shoreline. The wind is assumed to blow from the west to the east. The stack is assumed to be located somewhere on the X axis, either at (0,0) or at a (specified) point due east of this. All receptors should be defined downwind (east) of the source. Any receptors on the positive X axis will then be directly downwind

of the source. If your source is not exactly on the shoreline, it can be placed on the X axis at the distance you specify. For example, if you specify a stack-to-shore distance of 50 meters, and if there is a receptor at (120,0,0) (the third coordinate is the receptor height above ground) then the distance from the stack to the receptor is 70 meters. A receptor at (130,40,0) would be 80 meters downwind and 40 meters crosswind of the source. A receptor at (-100,0,0) would be upwind of the source and would therefore always have a computed concentration of 0.

(b) Receptor File

Upon executing SHLINE, you will first be asked for a receptor filename. Enter the name of a receptor file generated by RECGEN (see appendix C). NOTE: The positive X axis is directly downwind of the source.

(c) Output File

You will then be asked the name of an output file into which output will be placed. If the file does not exist, it will be created. If it does exist, it will be overwritten. If you wish to print the file, use the DOS PRINT program. The file is 80 columns wide.

NOTE: The concentration is outputted in 2 columns. The first is in units of micrograms/cubic meter. The second is in parts per million of sulphur dioxide. If the emissions are not SO₂, then the second concentration column should be ignored. If you wish, you may change the molecular weight in SHLINE.FOR (see appendices E and G) to the desired substance and recompile the code.

(d) Source and Meteorological Input

SHLINE will interactively ask you for various source and meteorological inputs. All of the inputs are required.

The required stack data is: stack height above ground, inner radius (**not** diameter), temperature (in degrees **celcius**, not kelvin), exit velocity, emission rate (in grams/second) and the distance from the stack to the shoreline. If you wish to enter an ambient stack temperature then enter a stack temperature of -999. This (clearly impossible) temperature indicates to SHLINE that you would like the stack temperature to be ambient. If you wish to enter your own computed buoyancy flux, then enter a stack temperature of -888. This (clearly impossible) temperature indicates to SHLINE that you would like to input a buoyancy flux. You will then be asked for a buoyancy flux.

The required meteorological data is: The TIBL profile parameter, the convective scaling velocity, the ambient 2 meter temperature (in degrees celcius), the wind speed, the Brunt-Vaisalla frequency, and an indication of whether the site is urban or rural. The TIBL profile parameter A has a range of 2 - 6. The convective scaling velocity has a range of 0.38 to 3 meters/second. The wind speed should preferably be the plume level wind speed but can be the 10 meter wind speed.

The Brunt-Vaisalla frequency has a range of 0.005 to 0.02 and can be computed by using

the following formula:

$$N = g * (\partial / \partial z) /$$

where:

g = universal gravitational constant = 9.8 (M/S/S)

= potential temperature (°C)

$\partial / \partial z$ = partial derivative of w.r.t. height

= gradient of potential temperature (°C/M)

6.3 A Sample SHLINE Run

A sample SHLINE receptor file might look like this:

```
.100000E+04 .0  
.200000E+04 .0  
.300000E+04 .0  
.....  
.200000E+05 .0 .0
```

which describes receptors (1000,0,0), (2000,0,0), (3000,0,0), ... (20000,0,0).

A sample dialogue with SHLINE might then be as follows, with the user replies in bold:

CAP Small-Scale Model: Shoreline Program, July 1990 Version

Please enter the RECEPTOR (.rec) filename [] **>SHLREC**

Please enter the output filename [] **>SH.OUT**

Please enter the following stack information:

- 1) Stack height (meters) [0] **>156.3**
- 2) Stack inner radius (meters) [] **>0.85**
- 3) Stack temperature (celcius) [0] **>102.2**
- 4) Stack exit velocity (meters/second) [0] **>10.1**
- 5) Stack emission rate (meters) [] **>123.435**
- 6) Distance from stack to shoreline (meters) [0] **>20**

Please enter the following meteorological information:

- 1) TIBL profile parameter A [] **>4.1**
- 2) Convective velocity scale W^* (meters/second) [] **>1.4**
- 3) Wind speed U (meters/second) [] **>3.4**
- 4) Ambient 2 meter air temperature T_a (celcius) [0] **>17**
- 5) Brunt-Vaisalla frequency N (1/S) [] **>0.01**
- 6) Is the site urban or rural? (U/R) [U] **>R**

Appendix A

APPENDIX A: File Management Facility Program (FM)

FM is used to create, modify or browse through a file for later use in the CAP programs. FM is designed to be easier to use than an unstructured text editor. The major difference over a text editor is that FM displays one record per screen, with each data field preceded by a header and trailed by its units, if any. (e.g. 'WIND SPEED 12.4 (METERS/SECOND)') The fields are displayed in three columns across the screen. Modifying a record involves simply moving from field to field using the <Enter> key. Some numerical fields are range-checked (e.g. 'MONTH' cannot be less than 1 or greater than 12).

A.1 Executing the Program

To execute FM from a floppy diskette, place the floppy diskette containing FM in drive A and type

A:\FM

Use drive B for your input and output files. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute FM from a hard disk, type:

C: and
CD \CAP

then invoke the CAP program by typing:

CAP

and choose option 5.

FM searches for its template (.tpl) and help (.hlp) files in first, the current directory. If they are not found then it searches the directory C:\CAP\FMUTIL. If they are not found there (or if the computer has no C drive) then it searches the directory A:\FMUTIL. Finally, it searches the directory B:\FMUTIL.

A.2 Fundamental Concepts

There are a number of conventions and procedures concerning FM and the file you wish to edit that should be understood before you begin an edit session.

(a) Option Line

After invoking the program, the cursor is placed on the option line. The option line begins

with an arrow (i.e. '==>'), and the cursor follows this arrow. Below the option line is a list of options. (e.g. 'Help', 'Quit'). To select an option, the cursor must be on the option line. Simply enter the option of your choice and press <Enter>. FM only recognizes the first letter of an option (the lone exception is described in A.2(b)). This means that you can save effort by simply entering 1 letter (e.g. 'H' for 'Help'). This also means that 'Q', 'Q#&%#*' and 'Quit' are identical, and that no two current options will start with the same letter.

(b) Chaining Commands

Except while in 'Insert' mode (section A.4(h)), commands may be "chained". Chaining allows a sequence of commands to be entered on the same line, separated by a semi-colon. This is the only exception to only the first letter of an option being recognized (see section A.2(a)). "Chaining" can save command entry time. For example, if you are in the "Browse Screen" and wish to exit FM entirely, there are two ways to proceed. One way is to enter 'Quit' and bring up the "Browse Entry Screen". Then enter 'Quit' again to bring up the initial screen. Then enter 'Quit' to exit FM. Another, faster, method is to enter 'Quit;Quit;Quit' or 'Q;Q;Q' on the option line of the "Browse Screen". The 3 quits are executed in sequence, and FM ends.

(c) Filename Extensions

Every file edited by FM must have an extension in the name. Furthermore, this must be a supported extension. Currently supported extensions are:

- 'bld' (BuiLDing)
- 'cfg' (worst case meteorology ConFiGuration)
- 'fun' (FUNction)
- 'hem' (Hourly stack EMissions)
- 'hts' (Hourly stack TemperatureS)
- 'hws' (Hourly stack exit velocitieS)
- 'lkt' (LaKe Temperature)
- 'met' (MET output)
- 'min' (Met INput)
- 'rec' (RECeptor)
- 'run' (RUN file)
- 'spi' (SPeCial receptors Input)
- 'src' (SouRCe)
- 'wci' (Worst Case meteorology Input)

The reason for this requirement relates to the user friendliness of FM. For every valid extension there is a template (.tpl) file. For example, for a '.src' file, there is a file called SRC.TPL. SRC.TPL tells FM what record layout a source file has, what the field header and units are and what range numeric fields must fall into. Do not edit the template files, or you will have to re-load them in from your original diskettes.

(d) Quitting and Getting Help

Selecting a particular option may have the effect of moving you to another screen. There are a number of different screens with various functions, but all of them (except one) have 'Quit' and 'Help' as an option. The lone exception is the "Modify/Create Screen". The reason for this is explained in sections A.4(c)-(e). In practice, being able to "Quit" from a screen means that the user can "back out of" a screen very easily.

(e) Editing Other Files with FM

Any file edited with FM should have been prepared with FM or the supplied utility programs METCO (appendix B) and RECGEN (appendix C). If you wish to edit another file, it should have a constant record length. This means that a non-blank character should occupy the last position in each record (or else DOS will store the file with varying length records to conserve space). Please refer to the record layout (appendix D) of the file in question for more information on using your own files.

(f) Numeric Data Entry

Some numeric data may be entered or displayed in E or D format. These formats are taken from the FORTRAN programming language, and are very similar to scientific notation. For example:

```
2.3   = 0.23E1
-.23  = -0.23E0
4000  = 0.4E+4
-0.07 = -.7E-1
```

Just think of "E" as representing "times ten to the power". The E can be replaced by D. In FORTRAN, E format signifies single precision (32 bits/number) and D signifies double precision (64 bits/number). If in doubt, use E format.

A.3 Browsing Through a File

The initial screen gives you a 'Browse' option. This means that you can examine a file without the risk of modifying or changing it in any way.

(a) Browse Entry Screen

Selecting 'Browse' places you in the "Browse Entry Screen". You now have the option of quitting ('Quit') and returning back to the initial screen. Additionally, you may ask for help ('Help'). However, the main purpose of this screen is to query you for a filename to browse through. Instead of entering an option, simply enter a filename on the option line. This file must exist. The program only considers the first letter in the user entry for an option, as explained in A.2(a). This means that the filename entered cannot begin with 'Q' or 'H', otherwise the program will assume that an option has been entered. (This drawback may be corrected for future versions of FM.)

(b) Browse Screen

After a correct filename has been entered in the "Browse Entry Screen", FM places you in the "Browse Screen". Here the records of the file are displayed, along with the filename (top left corner) and the number of the currently displayed record (top right corner). The record displayed upon entry to the "Browse Screen" is the first record in the file. There are 5 options related to viewing file:

- 1) 'Prev' - display the record previous to the current one
- 2) 'Next' - display the record after the current one
- 3) 'Top' - display the first record in the file
- 4) 'Bottom' - display the last record in the file (to a maximum of 9999 records)
- 5) 'Reci' - display any record you desire. You will be prompted for the number of the record that you wish to view.

(c) Ending a Browse Session

When you are finished browsing through a file, simply enter the option 'Quit'.

A.4 Modifying or Creating a File

The initial screen gives you a 'Modify/create' option. Select this option to modify an existing file or create a new one. Selecting 'Modify/create' places you in the "Modify/Create Entry Screen".

The "Modify/Create Entry Screen" is functionally identical to the "Browse Entry Screen" (section A.2(a)), with only minor differences. If the file does not exist, it will be created.

After you have entered a correct filename in the "Modify/Create Entry Screen", you will be placed in the "Modify/Create Screen". If the file you are editing does not exist, it will be created, and no record will be displayed. If it does exist, the first record will be displayed, just as in the "Browse Screen" (section A.2(b)), along with the record number, filename and a list of 12 options:

- 1) 'Prev' - display the record previous to the current one
- 2) 'Next' - display the record after the current one
- 3) 'Top' - display the first record in the file
- 4) 'Bottom' - display the last record in the file (to a maximum of 9999 records)
- 5) 'Reci' - display any record you desire. You will be prompted for the number of the record that you wish to view.
- 6) 'Delete' - delete a record or a range of records
- 7) 'Copy' - copy a record, a range of records, or an external file
- 8) 'Insert' - insert a new record or records
- 9) 'Abend' - exit FM without saving changes
- 10) 'Save' - save changes but do not exit FM
- 11) 'Update' - save change and exit FM
- 12) 'Help' - display help screen

(a) Creating a File

If the file did not exist upon entry to FM, data must be entered into the new file. You have two options for doing this. One way is to copy in an external file. This is done with the 'Copy' option (section A.4(g)). Another method for entering data is to use the 'Insert' option (section A.4(h)).

(b) Moving About the File

The first 5 options in the "Modify/Create Screen" are identical to the first 5 in the "Browse Screen", namely 'Prev', 'Next', 'Top', 'Bottom' and 'Reci' (described in section A.3(b)).

(c) Exiting Without Save

'Abend' causes FM to exit the "Modify/Create Screen" without saving the changes made to the file. 'Abend' should therefore be used with great caution. After an 'Abend' FM displays the "Modify/Create Entry Screen".

(d) Exiting With Save

'Update' causes FM to exit the "Modify/Create Screen", saving all the changes made to the file. FM will then display the "Modify/Create Entry Screen".

(e) Saving Changes Made to the File

'Save' is a safety feature of FM. Its effect is to write out all current changes made to the file, while staying in the "Modify/Create Screen" and allowing for further changes. If an 'Abend' is performed after a 'Save', only the changes made after the last 'Save' will be lost. The 'Save' option is very useful if there is concern that the computer may crash, hang or be unplugged. During a long edit session, only work since the last 'Save' would be lost.

(f) Deleting Records

If you select the 'Delete' option, FM displays the "Modify/Create Delete Screen" and gives you 2 further options for deleting records.

- 'CurrentDelete' deletes the currently displayed record and displays the next record in the file.

- 'BlockDelete' is used to delete a range of records. It must be entered twice to have an effect. The first time, the currently displayed record is flagged. Then return to the "Modify/Create Screen" where, you may note, the upper right corner has flagged the record with "*DEL*". Then move to the other record in the block, re-enter the "Modify/Create Delete Screen", and select 'BlockDelete' once more. The delete will then be performed. For example, if you wanted to delete records 4 through 12:

- 1) display record 4 in the "Modify/Create Screen"
- 2) select 'Delete'
- 3) select 'BlockDelete'
- 4) select 'Quit'
- 5) display record 12 in the "Modify/Create Screen"
- 6) select 'Delete'
- 7) select 'BlockDelete'

The block delete could just as easily have been performed backwards, from records 12 to 4. You can cancel any block delete after the first entry by going to the "Modify/Create Delete Screen" and selecting option 'RemovePendingDelete'. If a record has been deleted by mistake, the only options left are to either re-enter it manually or to 'Abend'. Note that selecting 'Delete' cancels any pending copies (see section A.4(g)) and selecting 'Copy' cancels any pending deletes.

(g) Copying Records

Selecting 'Copy' displays the "Modify/Create Copy Entry Screen". You are then given 3 basic options. In order to perform any copy, both a source (copy what?) and a target (copy where?) must be selected. Selecting 'Copy' cancels any pending deletes (see section A.4(f)).

Selecting 'Source' in the "Modify/Create Copy Entry Screen" places you in the "Modify/Create Copy Source Screen". From here, you can choose the source to be either the currently displayed record (by choosing 'CurrentCopy'), an external file with the same extension in the filename as the current file (by choosing 'ExternalFile') or a block of records in the current file (by choosing 'BlockCopy'). 'BlockCopy' selects the range of records in the same basic manner as 'BlockDelete', described in section A.4(f). The first and last records in the block are flagged by "***COPY***" in the upper right corner of the screen. When 'ExternalFile' is chosen, you will be asked for the name of the file you wish to copy in. If 'CurrentCopy' is chosen, the record to be copied will be flagged by "***COPY***" in the upper right corner.

The 'Target' option in the "Modify/Create Copy Entry Screen" places you in the "Modify/Create Copy Target Screen", and gives you 2 basic options. You may either select 'Before', and copy before the currently displayed record, or you may select 'After' and copy after the currently displayed record. The target record is flagged in the upper right corner with "***BEFORE***" or "***AFTER***". For example, if you select a target as before record 4, then go on to display record 3, it will be flagged with "***AFTER***".

In order to cancel a copy (either a source or target specification) simply select 'CancelPendingCopy' from the "Modify/Create Copy Screen".

To illustrate the copy command, suppose that you wish to append a file FB.REC to the end of a file FA.REC. You would perform these steps:

- 1) enter FM
- 2) select 'Modify/create'
- 3) enter filename 'FA.REC'
- 4) select 'Bottom'; You are now in the "Modify/Create Screen", looking at the last record in 'FA.REC'
- 5) select 'Copy'
- 6) select 'Target'
- 7) select 'After'
- 8) select 'Source'
- 9) select 'ExternalFile'
- 10) enter filename 'FB.REC'; The copy will now be performed

Now suppose that these two files together have 500 records, and you wish to duplicate records 1 to 7 before record 130:

- 1) select 'Top'
- 2) select 'Copy'
- 3) select 'Source'
- 4) select 'BlockCopy'
- 5) select 'Quit'
- 6) select 'Reci'
- 7) enter record number '7'
- 8) select 'copy'
- 9) select 'Source'
- 10) select 'BlockCopy'
- 11) select 'Quit';
- 12) select 'Reci'
- 13) enter record number '130'
- 14) select 'Copy'
- 15) select 'Target'
- 16) select 'Before'; the block copy will now be performed

(h) Modifying Fields or Inserting Individual Records

Selecting 'Insert' in the "Modify/Create Screen" displays the "Modify/Create Insert Screen". Three basic options are available to you at this point.

- Select 'BeforeThisRecord' to create a new record prior to the one currently displayed. This option can be used if there are no records in the file.
- Select 'AfterThisRecord' to create a new record following the one currently displayed. This option should also be used if there are no records in the file.
- Select 'ModifyThisRecord' to modify the fields of the currently displayed record. Do not use this option if there are no records in the file.

Once one of these three options are chosen, you will be placed in the insert screen. From

here, you have the option to request both 'Help' and 'Quit', as usual. But you also have 2 other special options. Normally, pressing <Enter> on a blank option line produces an error. But in the insert screen, <Enter> moves the cursor to the first field of the record on display. You can then type a new value in, followed by <Enter>, and the entry will be validated and stored. In this manner, a particular field can be changed. Pressing <Enter> without entering a value for a field moves the cursor to the next field. When you are on the last field of the record, <Enter> moves you back to the option line. NOTE: It is only possible to choose an option from the option line.

Once you have finished with a record, you may press 'Quit' to return to the "Insert Entry Screen", or you may choose the other special option. The option 'Next' creates a new record after the one you were just editing, and places in its fields the values in the record you were just editing. In this manner, you can create a variety of similar records easily. For example, if you wanted to create 10 meteorological input (.min) records, all identical except for the wind speed:

- 1) select option 'Insert' in the "Modify/Create Screen"
- 2) select 'AfterThisRecord' in the "Modify/Create Insert Entry Screen"
- 3) press <Enter> and move from field to field, entering data as required until you have finished with the record and are back on the option line
- 4) select 'Next'. A new record will be displayed (check the record number) with the same field values as the old one
- 5) move to the wind speed field and change it, then return to the option line by pressing <Enter> repeatedly
- 6) perform steps 4 and 5 eight more times
- 7) select 'Quit' twice to return to the "Modify/Create Screen"

These changes would not be preserved on disk unless a 'Save' or 'Update' was entered in the "Modify/Create Screen".

When inserting data into fields, you have the option of entering numeric data (integer, real, E format, D format) in any manner (e.g. real into integer, E format into real, etc.) FM performs the appropriate conversion. Note that only a certain number of characters are allocated for each field. So, for example, once you have typed the sixth character in a six character wide field FM will process your entry without you having to press <Enter>.

Appendix B

APPENDIX B: Meteorological File Conversion Program (METCO)

The purpose of the CAP meteorological file conversion program is to disable (flag) the higher level (alternate) wind speed field. If you have any meteorological input files that were used by the single-source-only version of the proposed regulation 308 models (prior to the June 1988 version), then this utility can be used to convert the file for use in the program METM (section 4). Note that the file also can be modified by using the program FM (appendix A). Simply set the alternate wind speed to -1.0 meters/second for all the records.

(a) Executing the Program

To execute METCO from a floppy diskette, place the floppy diskette containing METCO in drive A and type

```
A:\METCO
```

Use drive B for your input and output files. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute METCO from a hard disk, type:

```
C:          and  
CD \CAP
```

then invoke the CAP program by typing:

```
CAP
```

and choose option 6.

(b) Input Filename

Supply the name of the file which you wish to convert. Note that this file must exist prior to running the program.

(c) Output Filename

Supply the name of the output file to which you wish to direct the results. This file must end with the extension '.min' (refer to your DOS manual for more information concerning extensions). The file need not exist. If it does not exist, the program will create it. If it does exist, the program will overwrite it. You will be given the option of exiting the program if you do not wish to overwrite the file.

(d) A Sample METCO Run

A sample METCO dialogue might appear as follows:

CAP Small-Scale Model: Met File Conversion Program, July 1990 Version

This program converts the meteorological input file so that the
higher level wind (alternate wind) is DISABLED (flagged).

Enter the input filename >**M1.MIN**

Enter the output filename >**M2.MIN**

Appendix C

APPENDIX C: Receptor File Generation Program (RECGEN)

The purpose of the CAP receptor file generation program is to generate a file of receptors (i.e. (X,Y,Z) locations) for use in the dispersion program GAS (see section 6). Note that GAS generates its own receptor file in a downwind maximum single source run. It is possible to use FM (see appendix A) to generate a receptor file. But for many evenly spaced receptors, using RECGEN is a much faster method.

C.1 Executing the Program

To execute RECGEN from a floppy diskette, place the floppy diskette containing RECGEN in drive A and type

A:\RECGEN

Use drive B for your output file. You may refer to files in drive B by prefacing the filename with 'B:'.

To execute RECGEN from a hard disk, type:

C: and
 CD \CAP

then invoke the CAP program by typing:

CAP

and choose option 7.

Upon executing RECGEN, you will be asked to enter the name of the file to which you would like the output directed. It must have the extension '.rec'. If the file exists, you will be given the option of exiting RECGEN rather than overwriting the file.

C.2 Receptor Layout

Enter either 'S' for straight-line receptors, 'R' for a rectangular grid of receptors or 'C' for crossed lines receptors.

(a) Straight Line Receptors

These receptors are oriented either east-west or north-south, and run along 1 dimension only. If the orientation is east-west, the Y values are all 0. If the orientation is north-south, the X values are all 0. In other words, the receptors occur along the axes.

(b) Rectangular Grid Receptors

A rectangular grid is an array of receptors in the X and Y directions. All the receptors generated are listed in the output file in a column, scanning west to east and then south to north. In other words, the first point is the south-west corner. The second point is just east of the south-west corner. The second last point is just west of the north-east corner, and the last point is the north-east corner.

(c) Crossed Lines Receptors

These receptors combine 2 straight line sets of receptors, one oriented east-west and the other north-south. The east-west line occurs on the X axis. The north-south line need not intersect the east-west one. For example, the east west line could run from 100 to 200 meters, and the north south line could run from 200 to 400 meters, at an X value of 500 meters. If the lines do intersect, they need not do so at an east-west receptor. For example, If the east-west line is from 100 to 1000 meters with a 100 meter spacing, and the north-south line is from -100 to 100 meters with a 100 meter spacing, you can specify a crossing at 124.3 meters, even though there is no east-west receptor at 124.3 meters. This is useful in allowing you to specify crosswind receptors at a particular downwind location.

C.3 Receptor Spacing and Heights

Each of the 3 receptor layout options requires you to input a receptor spacing. The spacing is the distance between successive receptors, along an axis. For example, the straight line option C.1(a) with a westmost point at 100 meters, an eastmost point at 400 meters and a spacing of 100 meters would produce the receptors (100,0), (200,0), (300,0) and (400,0). The spacing need not divide evenly into the start-to-end distance. If it does not, however, the last point will not be evenly spaced. For the rectangular grid or crossed-lines options, the east-west spacing need not equal the north-south spacing.

All options require the entry of a receptor height above ground, in meters. This height is applied to all the receptors generated. Enter 0 meters for a ground level concentration calculation in GAS.

C.4 Modifying the Output File

The output file produced by RECGEN can be modified by FM (appendix A). Individual receptors (and receptor heights) can be modified. Two or more receptor output files can be combined (using the COPY EXTERNAL FILE option in FM).

C.5 A Sample RECGEN Run

A sample RECGEN run might appear as follows:

CAP Small-Scale Model: Receptor Generation Program, July 1990 Version

Please enter the RECEPTOR (.rec) filename [] >REC1.REC

Will you want a RECTANGULAR grid, STRAIGHT line
or CROSSED lines receptors? (R/S/C) [] >**R**

Enter the westmost X coordinate [0] >**-200**

Enter the eastmost X coordinate [0] >**100**

Enter the east-west grid interval [] >**100**

Enter the southmost Y coordinate [0] >**-10**

Enter the northmost Y coordinate [0] >**20**

Enter the north-south grid interval [] >**10**

Enter a height for all receptors (meters, usually 0) [0] >**0**

The results would be found in file REC1.REC, and are listed below:

```

-.200000E+03-.100000E+02 .0
-.100000E+03-.100000E+02 .0
 .0          -.100000E+02 .0
 .100000E+03-.100000E+02 .0
-.200000E+03 .0          .0
-.100000E+03 .0          .0
 .0          .0          .0
 .100000E+03 .0          .0
-.200000E+03 .100000E+02 .0
-.100000E+03 .100000E+02 .0
 .0          .100000E+02 .0
 .100000E+03 .100000E+02 .0
-.200000E+03 .200000E+02 .0
-.100000E+03 .200000E+02 .0
 .0          .200000E+02 .0
 .100000E+03 .200000E+02 .0

```


Appendix D

APPENDIX D: Record Layouts

There are 5 field types. Type I is integer, type F is real, type A is alphanumeric, type L is logical (T or F) and type E is exponential (see appendix A.2(f)).

(a) Average File (.avg)

Record Length = 43

Fortran Format: (3(1X, F9.2), 1X, E12.6)

FIELD	UNITS	COLUMNS	TYPE
Distance East of (0,0)	(M)	2-10	F
Distance North of (0,0)	(M)	12-20	F
Height Above Ground	(M)	22-30	F
Average Concentration	(UG/M**3)	32-43	F

(b) Building File (.bld)

Record Length = 209

Fortran Format: (F10.3, F10.3, F7.3, 20F9.3, I2)

FIELD	UNITS	COLUMNS	TYPE	DUMMY VALUE
X Value of Centre of Building	(M)	1-10	F	
Y Value of Centre of Building	(M)	11-20	F	
Building Height	(M)	21-27	F	
X Value of Corner Pt. 1	(M)	28-36	F	
Y Value of Corner Pt. 1	(M)	37-45	F	
X Value of Corner Pt. 2	(M)	46-54	F	
Y Value of Corner Pt. 2	(M)	55-63	F	
...				
X Value of Corner Pt. 10	(M)	190-198	F	0
Y Value of Corner Pt. 10	(M)	199-207	F	0
Number of Corner Points		208-209	I	

NOTES: 1) There should be 1 building record for each building.

- 2) The Building Number field in the source file refers to the same record number in the building file. For example, if a source has a building number of 5, then it is associated with the 5th record in the building file. If the source has no building, then set the Building Number to 0.
- 3) If Stack Height is less than 2 times Building Height, the dispersion program will perform a near surface building wake calculation. The height and widths of the building (in the '.bld' file) do not affect dispersion calculations if the Stack Height is greater than 2 times the Building Height.

- 4) The building should have at least 3 corner points (unless it is used in a straight downwind run; in that case, insure that there is a building width that faces east).

(c) Dump File (.dmp)

Record Length = (varies from 4 to 256)

Fortran Format: (64A4)

FIELD	UNITS	COLUMNS	TYPE
Concentration for met case 1, receptor 1	(UG/M**3)	1-4	A
Concentration for met case 1, receptor 2	(UG/M**3)	5-8	A
...			
Concentration for met case 1, receptor N	(UG/M**3)	(4*N-3)-(4*N)	A

NOTES: 1) The first record contains 2 free-format integers: First, the number of receptors used in the GAS run. Second, the number of concentrations outputted per record (usually 64). These 2 numbers can be used in reading the dump file by a program.

- 2) The concentrations are outputted in the form of 4 byte (32 bit) real numbers in IEEE format.
- 3) The maximum allowed record length is 256 bytes. This means that a maximum of 64 concentrations are outputted per record. If there are more than 64 receptors, the extra concentrations are spilled over onto subsequent records. If there are an odd number of receptors (not divisible by 64) then the last record spilled will have less than 256 bytes.
- 4) Each meteorological case is outputted as a (possibly spilled) set of concentrations. There is one set outputted per meteorological case.

(d) Function File (.fun)

Record Length = 124, Direct Access

Fortran Format: (I1, 1X, I2, 2(1X, I1), 3(1X, E12.6), 1X,
I1, 1X, F6.1, 7(1X, I1), 1X, E12.6, 3(1X,
I1), 3(1X, E12.6))

FIELD	UNITS	COLUMNS	TYPE	DUMMY VALUE
Hourly Max Flag		1	I	
Moving Average Hours		3-4	I	
Julian Day Max Flag		6	I	
Average Over All Hours				
Grid Flag		8	I	
Minimum X for Downwind Search	(M)	10-21	E	0

Downwind Search Limit	(M)	23-34	E	0
Height of Receptor for Downwind Search	(M)	36-47	E	0
Percentage Contribution Flag		49	I	
Clockwise Receptor Rotation	(DEGREES)	51-56	F	0
Special Receptors Input Flag		58	I	
Special Receptors Output Flag		60	I	
Fine Grid Search using Old Hourly Max Flag		62	I	
Hourly Emission Flag		64	I	
Hourly Stack Temperature Flag		66	I	
Hourly Exit Velocity Flag		68	I	
Building File Flag		70	I	
Geometric Mean	(UG/M**3)	72-83	E	
Dump File Flag		85	I	
Shoreline within 15 km Flag		87	I	
Lake Temperature File Flag		89	I	
X position of a point on the shoreline	(M)	91-102	E	
Y position of a point on the shoreline	(M)	104-113	E	
Azimuth angle of shoreline	(DEG.)	115-124	E	

NOTES: 1) Flags disable the function if they equal 0 and enable the function if they equal 1.

- 2) 'Downwind Search Limit' is ignored if 'Minimum X for Downwind Search' is 0. In this case, a receptor file will be required by GAS.
- 3) The Clockwise Receptor Rotation rotates the entire grid clockwise by the amount specified. Set to non-zero if you wish to re-orient the grid so that it is not aligned with the X and Y axes. (You will normally want this to be zero.)
- 4) The Geometric Mean is equal to 0 if no geometric mean calculation is required. Otherwise, it is equal to the background concentration in micrograms/cubic meter.
- 5) The Moving Average Hours is equal to 0 if no moving average calculation is required. Otherwise, it is equal to the number of hours over which the moving average is computed (e.g. 8 or 24).
- 6) The X and Y position of a point on a shoreline, together with the azimuth angle of the shoreline is used to define the shoreline.
- 7) A shoreline calculation will not be performed unless both 'Shoreline within 15 km Flag' and 'Lake Temperature File Flag' are set to 1.
- 8) The Special Receptor Input Flag specifies whether the special receptors are inputted interactively (0) or through a file (1). The Special Receptor Output Flag specifies whether or not special receptor output is required. If it is set to 0, the Special Receptor Input Flag is ignored.

(e) Geometric Mean File (.gmn)

(same format as Average File (.avg))

(f) Hourly Stack Emission Rate File (.hem)

Record Length = (varies)

Fortran Format: (50E12.6)

FIELD	UNITS	COLUMNS	TYPE
Emission rate for Source 1	(G/S)	1-12	E
Emission rate for Source 2	(G/S)	13-24	E
...			
Emission rate for Source N	(G/S) (12*N-11)-(12*N)		E

NOTES: 1) If this file is used, then there MUST be 1 record per meteorological record.

2) N equals the numbers of sources inputted.

(g) Hourly Stack Temperature File (.hts)

(Same format as Hourly Stack Emissions Rate File, except units in °C)

(h) Hourly Stack Exit Velocity File (.hws)

(Same format as Hourly Stack Emissions Rate File, except units in meters/second)

(i) Lake Temperature File (.lkt)

Record Length = 13

Fortran Format: (I2, I2, I2, I2, I2, I3)

FIELD	UNITS	COLUMNS	TYPE
Year		1-2	I
Starting Month		3-4	I
Starting Day	5-6	1	
Ending Month	7-8	1	
Ending Day	9-10	1	
Lake Temperature	(Celcius)	11-13	I

NOTES: 1) There is one record for each distinct lake temperature.

2) The records MUST be ordered by date

3) The file will only be used in shoreline calculations.

4) If a shoreline calculation is to be made but there is no lake temperature

- 5) available for that date, GAS will terminate execution and report an error.
Shoreline calculations are only considered if the date falls between April 15 and Oct 15.

(j) Meteorological Output File (.met)

Record Length = 133, Direct Access

Fortran Format: (I2, I2, I2, I2, F6.3, I3, F6.2, F6.3,
I2, I1, I4, I3, F5.2, F6.2, F7.5, F5.2,
F5.2, F7.2, I1, F7.2, F7.2, F7.2, F6.3,
F9.3, F7.4, F7.4, F4.1, A1, I3)

FIELD	UNITS	COLUMNS	TYPE
Year		1-2	I
Month		3-4	I
Day		5-6	I
Hour	(GMT)	7-8	I
Wind Speed at Higher Level	(M/S)	9-14	F
Temperature at 2 meters	(C)	15-17	I
Wind Direction Azimuth	(DEG)	18-23	F
Original 10 meter Wind Speed	(M/S)	24-29	F
Cloud Cover	(8ths)	30-31	I
Snow Cover		32	I
Mixed Layer Height	(M)	33-36	I
IDATA		37-39	I
Latitude	(DEG)	40-44	F
Longitude	(DEG)	45-50	F
Surface Roughness	(M)	51-57	F
Sunrise	(GMT)	58-62	F
Sunset	(GMT)	63-67	F
Surface Heat Flux	(W/M/M)	68-74	F
Stability		75	I
Convective BLH	(M)	76-82	F
Neutral BLH	(M)	83-89	F
Stable BLH	(M)	90-96	F
Wind Speed at 10 meters	(M/S)	97-102	F
Monin-Obukhov Length	(M)	103-111	F
Friction Velocity	(M/S)	112-118	F
Convective Velocity Scale	(M/S)	119-125	F
Wind Randomization Amt.	(DEG.)	126-129	F
Rural/Urban Flag		130	A
IFLAG		131-133	I

NOTES: 1) The HOUR is entered in GREENWICH MEAN TIME on a 24 hour (0-23)

- clock. GMT equal EST + 5 hours.
- 2) Entering a Higher Level Wind Speed of 0 meters/second will result in it being used. If you DO NOT have a higher level wind, enter -1.0 as a dummy value.
 - 3) STABILITY flag: 1=CONVECTIVE, 2=NEUTRAL, 3=STABLE.
 - 4) For STABLE cases, the 'Original 10 meter Wind Speed' MUST be at least 1.5 meters/second. When creating your own met record, set it equal to 'Wind Speed at 10 meters' for STABLE cases.
 - 5) IFLAG indicates the validity of output. The record is not valid (and will be treated as such by GAS) if IFLAG=800 or 999. If you are creating your own met file, set IFLAG=0.
 - 6) The Rural/Urban Flag equals 'R' if the site is rural and 'U' if the site is urban.
 - 7) 'Wind Randomization Amount' is 0 if no wind direction randomization has occurred. Otherwise it equals the reporting interval for wind directions, e.g. it equals 10 if wind directions are reported every 10 degrees.
 - 8) The required fields for a GAS run are:
 - Year, Month, Day (if shoreline case)
 - Temperature at 2 meters
 - Original 10 meter Wind Speed (STABLE only)
 - Wind Direction Azimuth (if using receptor file)
 - Surface Roughness
 - Stability
 - one of Neutral, Convective or Stable BLH
 - Wind Speed at 10 meters
 - Monin-Obukhov Length (if not a Neutral case)
 - Friction Velocity
 - Convective Velocity Scale (CONVECTIVE only)
 - IFLAG

(k) Meteorological Input File (.min)

Record Length = 70, Direct Access

Fortran Format: (I2, I2, I2, I2, 8X, F6.3, I4, E14.8,
E14.8, 2X, I2, 2X, I2, I4, I4)

FIELD	UNITS	COLUMNS	TYPE	DUMMY VALUE
Year		1-2	I	
Month		3-4	I	
Day		5-6	I	
Hour	(GMT)	7-8	I	
Wind Speed at Higher Level	(M/S)	17-22	F	-1
Temperature at 2 meters	(C)	23-26	I	
Wind Direction Azimuth	(DEG)	27-40	E	
Wind Speed at 10 meters	(M/S)	41-54	E	
Cloud Cover	(8ths)	57-58	I	
Snow Cover		61-62	I	

Mixed Layer Height	(M)	63-66	I
IDATA		67-70	I

- NOTES: 1) The HOUR is entered in GREENWICH MEAN TIME, on a 24 hour (0-23) clock. GMT equals EST + 5 hours.
- 2) Entering a Higher Level Wind Speed of 0 meters/second will result in it being used. If you do not have a higher level wind, enter -1.0 as a dummy value.
- 3) A Snow Cover of 0 means that there is no snow. Entering 1 means that there is snow. These are the only two acceptable values.
- 4) A Mixed Layer Height is only required if the met case will turn out to be CONVECTIVE. Stable and Neutral cases calculate their own Boundary Layer Heights.
- 5) IDATA is a flag used in analyzing large amounts of met input data. It should be kept to 0 for your own prepared data.

(l) Percentage Contribution File (.per)

Record Length = (varied)

Fortran Format: (3(1X, F9.2), 1X, E12.6, 1X, 250F5.3)

FIELD	UNITS	COLUMNS	TYPE
Distance East of (0,0)	(M)	2-10	F
Distance North of (0,0)	(M)	12-20	F
Height Above Ground	(M)	22-30	F
Concentration	(UG/M**3)	32-43	E
Fraction of Conc. from Source 1		45-49	F
Fraction of Conc. from Source 2		50-54	F
...			
Fraction of Conc. from Source N		(40-44)+5N	F

NOTE: There are as many 'Fractions' as sources.

(m) Receptor File (.rec)

Record length = 36, Direct Access

Fortran Format: (E12.6, E12.6, E12.6)

FIELD	UNITS	COLUMNS	TYPE
Distance East of (0,0)	(M)	1-12	E
Distance North of (0,0)	(M)	13-24	E
Height Above Ground	(M)	25-36	E

(n) Run File (.run)

Record Length = 40, 21 Records in File
Fortran Format: (A40)

- Record 1) Summary (.sum) filename (output)
2) Detail (.det) filename (output)
3) Source (.src) filename (input)
4) Percentage Contrib. (.per) filename (output)
5) Receptor (.rec) filename (input)
6) Meteorological (.met) filename (input)
7) Hourly Maximum (.hmx) filename (output)
8) Annual Average (.avg) filename (output)
9) Julian Day Maximum (.jdm) filename (output)
10) Function (.fun) filename (input)
11) Moving Average (.mov) filename (output)
12) Special Receptor Input (.spi) filename (input)
13) Special Receptor Output (.spo) filename (output)
14) Old Hourly Maximum (.hmx) filename (input)
15) Hourly Emissions (.hem) filename (input)
16) Hourly Stack Temp. (.hts) filename (input)
17) Hourly Exit Velocity (.hws) filename (input)
18) Building Dimensions (.bld) filename (input)
19) Geometric Mean (.gmh) filename (output)
20) Dump (.dmp) filename (output)
21) Lake Temperature (.lkt) filename (input)

NOTES: 1) To not use or blank out a file, let the filename be 'NUL'.

2) If the function file does not exist, GAS will create it and prompt you for input.

(o) Special Receptor Input File (.spi)

(Same format as Receptor file, but maximum of 10 records)

(p) Special Receptor Concentration Output File (.spo)

Record Length = (varies)

Fortran Format: (10E13.6)

FIELD	UNITS	COLUMNS	TYPE
Concentration for			
Source 1	(UG/M**3)	1-13	E
Concentration for			
Source 2	(UG/M**3)	14-25	E
...			
Concentration for			
Source N	(UG/M**3)	(13*N-12)-(13*N)	E

NOTE: N equals the numbers of special receptors inputted, and it cannot exceed 10.

(q) Source File (.src)

Record Length = 133, Direct Access

Fortran Format: (A10, A32, F9.2, F9.2, F6.2, F7.4, F7.1,
F7.3, E12.6, F8.3, F8.3, I3, F7.2, F7.2, I1)

FIELD		UNITS	COLUMNS	TYPE	DUMMY	VALUE
Source Identification			1-10	A	(blank)	
Source Name			11-42	A	(blank)	
Distance East of (0,0)	(M)		43-51	F		0
Distance North of (0,0)	(M)		52-60	F		0
Stack Height	(M)		61-66	F		
Stack Radius	(M)		67-73	F		
Stack Temperature	(Celcius)		74-80	F	-999,-888	
Exit Velocity	(M/S)		81-87	F	-888	
Emission Rate	(G/S)		88-99	E		
Buoyancy Flux	(M4/S3)		100-107	F		0
Momentum Flux	(M4/S2)		108-115	F		0
Building Number			116-118	I		0
Initial Total Vertical Plume Height	(M)		119-125	F		0
Initial Total Horizontal Plume Width	(M)		126-132	F		0
Complex Terrain Flag			133	I		0

- NOTES: 1) If Stack Temperature is set to the dummy value of -999.0, it indicates that stack temperature should be set to the ambient air temperature in the dispersion program. If the Stack Temperature is set to the dummy value of -888.0 it indicates that the buoyancy flux in the dispersion program should be taken from Buoyancy Flux, above, and that the stack temperature in the dispersion program should be set to ambient. The Buoyancy Flux field, above, is ignored if the stack temperature is not set to -888.0
- 2) If Exit Velocity is set to the dummy value of -888.0 it indicates that the momentum flux in the dispersion program should be taken from Momentum Flux, above, and that the exit velocity in the dispersion program should be set to 0. The Momentum Flux field, above, is ignored if the exit velocity is not set to -888.
- 3) If Stack Height is less than 2 times Building Height, the dispersion program will perform a near surface building wake calculation. The height and widths of the building (in the '.bld' file) do not affect dispersion calculations if the Stack Height is greater than 2 times the Building Height.
- 4) The stack radius CANNOT be less than or equal to 0 meters.
- 5) All receptors are oriented with respect to location (0,0).
- 6) The Building Number refers to the record in the Building (.bld) file. For example, if the Building Number is 5, then the 5th building described in the building file corresponds to the source. If there is no building, set the

Building Number to 0.

- 7) The Complex Terrain Flag is 0 if there is no complex terrain and 1 if there is complex terrain at the site.

(r) Worst Case Met Input File (.wci)

Record Length = 95

Fortran Format: (F6.2, F7.1, F7.4, F7.3, F7.2, F7.2, F8.2,
F8.2, F7.4, F8.3, F8.3, F7.2, F7.2, A1)

FIELD	UNITS	COLUMNS	TYPE	DUMMY	VALUE
Stack Height	(M)	1-6	F		
Stack Temperature	(Celcius)	7-13	F	-999,-888	
Stack Radius	(M)	14-20	F		
Exit Velocity	(M/S)	21-27	F	-888	
Building Height	(M)	28-34	F		
Building Width	(M)	35-41	F		
Nearest Distance	(M)	42-49	F		
Farthest Distance	(M)	50-57	F		
Surface Roughness	(M)	58-64	F		
Buoyancy Flux	(M4/S3)	65-72	F	0	
Momentum Flux	(M4/S2)	73-80	F	0	
Initial Total Vertical Plume Height	(M)	81-87	F	0	
Initial Total Horizontal Plume Spread	(M)	88-94	F	0	
Rural/Urban Flag		95	A		

- NOTES: 1) If Stack Temperature is set to the dummy value of -999.0, it indicates that stack temperature should be set to the ambient air temperature in WCM. If the Stack Temperature is set to the dummy value of -888.0 it indicates that the buoyancy flux in WCM program should be taken from Buoyancy Flux, above, and that the stack temperature in WCM should be set to ambient. The Buoyancy Flux field, above, is ignored if the stack temperature is not set to -888.
- 2) If Exit Velocity is set to the dummy value of -888.0 it indicates that the momentum flux in WCM should be taken from Momentum Flux, above, and that the exit velocity in WCM should be set to 0. The Momentum Flux field, above, is ignored if the exit velocity is not set to -888.
- 3) If Stack Height is less than 2 times Building Height, WCM will perform a near surface building wake calculation. The height and widths of the building do not affect dispersion calculations if the Stack Height is greater than 2 times the Building Height.
- 4) If you wish to use the initial total vertical plume height, set the building height to -1. If you wish to use the initial total horizontal plume width, set the building width to -1.
- 5) The stack radius CANNOT be less than or equal to 0 meters.

- 6) All receptors are oriented with respect to location (0,0), the assumed location of the source.
- 7) The Rural/Urban Flag equals 'R' if the site is rural and 'U' if the site is urban.

(s) Worst Case Meteorology Configuration File (WCM.CFG)

Record Length = 4

Fortran Format: (4L1)

FIELD	UNITS	COLUMNS	TYPE
Fixed Wind Speed	(meters/second)	1	L
Fixed Convective			
Boundary Layer Height	(meters)	2	L
Emission Rate	(grams/second)	3	L
Receptor Height			
Above Ground	(meters)	4	L

NOTES: 1) A value of 'T' turns on the optional value.

2) If WCM does not find this file, it assumes that all the values are 'F'.

3) This file is only used on interactive input.

Appendix E

APPENDIX E: Routine Calling Structures

The CAP modules each call a number of subroutines, which may in turn call other subroutines and functions. In the following sections, the first routine listed is the main routine, and the name in the brackets is the source filename, minus the '.for' extension. So, for example, 'GETFILE (GF)' means that the subroutine GETFILE is found in the DOS file 'GF.FOR'. Also, an indented routine is called by the routine from which it is directly indented.

(a) METM Calling Structure

```
METM (METM)
  MINIT (MINIT)
  HFLUX (HFLUX)
  NDAY (NDAY)
  GETFILE (GF)
  MWRITE (GF)
  GETIC (GF)
  GETR (GF)
  RANINI (RANFIB)
  RANLIN (RANFIB)
  RANFIB (RANFIB)
  CON2 (CON2)
  NEU2 (NEU2)
  STB2 (STB2)
```

(b) WCM Calling Structure

```
WCM (WCM)
  SCHAR (SCUTIL)
  SCHARF (SCUTIL)
  SCCLR (SCUTIL)
  GFILES (WCM)
  GETIC (GF)
  GETFILE (GF)
  MWRITE (GF)
  GREET (WSUBS)
  SCCLR (SCUTIL)
  SCHAR (SCUTIL)
  SCHARF (SCUTIL)
  GETS (WSUBS)
  SCCLR (SCUTIL)
  SCHAR (SCUTIL)
  SCHARF (SCUTIL)
  GETNUM (WSUBS)
```

- SCHAR (SCUTIL)
- SCHARF (SCUTIL)
- MESSG (WSUBS)
 - SCHAR (SCUTIL)
- SURFR (WSUBS)
 - SCCLR (SCUTIL)
 - SCHAR (SCUTIL)
 - SCLINE (SCUTIL)
- GETNUM (WSUBS)
 - SCHAR (SCUTIL)
 - SCHARF (SCUTIL)
- RPRINT (WCM)
 - SCNUM (SCUTIL)
 - SCHAR (SCUTIL)
- TABLE (WSUBS)
 - SCHAR (SCUTIL)
- SINFO (WSUBS)
 - SCCLR (SCUTIL)
 - SCHAR (SCUTIL)
 - SCNUM (SCUTIL)
- SDEP (SDEP)
 - INIT (SDEP)
 - SET (SDEP)
 - CONV (CO)
 - CU (CO)
 - CLU (CO)
 - FZL (CO)
 - CRISE (CO)
 - ANOND (CO)
 - CSURF (CO)
 - ANOND (CO)
 - CELE (CO)
 - CALXI (CAL)
 - ERF (ERF)
- NEUTRAL (NEUT)
 - NSUR (NEUT)
 - NWIND (NEUT)
 - NRISE (NEUT)
 - NSUR (NEUT)
 - NELE (NEUT)
 - NSUR (NEUT)
- STABLE (STB)
 - SRISE (STB)
 - SSUR (STB)
 - STEX (STB)
 - SELE (STB)
 - STEX (STB)

SELE (STB)

(c) GAS Calling Structure

GAS (GAS)

- RUNEXT (RT)
 - ERRWRT (LMET)
 - PFUN (PFUN)
- GETFILE (GF)
 - MWRITE (GF)
- SPEC (SPEC)
 - SPT (SPEC)
 - GETIC (GF)
- RUNEXF (RF)
 - GETFILE (GF)
 - MWRITE (GF)
 - ERRWRT (LMET)
 - FUNEXF (F)
 - ERRWRT (LMET)
 - GETFILE (GF)
 - MWRITE (GF)
 - PFUN (PFUN)
 - GETIC (GF)
 - GETR (GF)
 - FUNEXT (F)
 - ERRWRT (LMET)
 - GETFILE (GF)
 - MWRITE (GF)
 - PFUN (PFUN)
- LMET (LMET)
 - INITG (I)
 - INF (INF)
 - RSRC (RS)
 - ERRWRT (LMET)
 - WIND (W)
 - ROTATE (W)
 - MOVING (MO)
 - ERRWRT (LMET)
 - ARRMAX (AR)
 - AVGARR (AV)
 - ERRWRT (LMET)
 - JDMMAX (J)
 - ERRWRT (LMET)
 - BWIDTH (BW)
 - ROTATE (W)
 - ERRWRT (LMET)
 - ERRWRT (LMET)

- PFUN (PFUN)
- ROTATE (W)
- GEOMN (GE)
 - ERRWRT (LMET)
- RECIND (RE)
 - RISE (RISE)
 - CONRI (C)
 - NEURI (N)
 - STBRI (S)
- LSRC (LSRC)
 - RECD (RD)
 - STBELE (S)
 - STBSUR (S)
 - NEUELE (N)
 - NEUSUR (N)
 - CONSUR (C)
 - CONELE (C)
 - CALXI (CAL)
 - ERF (ERF)
- RECG (RG)
 - STBELE (S)
 - STBSUR (S)
 - NEUELE (N)
 - NEUSUR (N)
 - CONSUR (C)
 - CONELE (C)
 - CALXI (CAL)
 - ERF (ERF)
 - SHOREL (SH)
 - SIMP (SH)
- EVAL (SH)

(d) SHLINE Calling Structure

- SHLINE (SHLINE)
 - GETFILE (GF)
 - MWRITE (GF)
 - SHOREL (SH)
 - SIMP (SH)
 - EVAL (SH)

Appendix F

APPENDIX F: Common Blocks

The common blocks in the source code are each in separate files. The filename is the composed of the common block name with a '.blk' extension. For example, block 'CONST' is found in file 'CONST.BLK'. An 'INCLUDE' statement is placed in the source code to include the common block at compile time.

Because of PARAMETER statements in some of these '.blk' files, it is necessary to include some common blocks in pairs. Any routine that contains block 'AVGLOC' must precede its declaration of this common block by the declaration of block 'RECEP'. Also, any routine that contains blocks 'SRCARR', 'SHRVAR' or 'BLDG' must precede its declaration of these common blocks by the declaration of block 'SRCINF'.

The following sections describe, in general terms, the contents of each common block and list the routines that use the block. To find out which DOS file contains the routines listed, refer to appendix E.

(a) Block 'AVGLOC'

Contains average concentration intermediate data for GAS

Routines found in:

AVGARR LMET

(b) Block 'BLDG'

Contains building dimension information for GAS

Routines found in:

BWIDTH RECIND RSRC WIND

(c) Block 'CONMET'

Contains precalculated met-dependant convective values for WCM and GAS

Routines found in:

CALXI CU CONSUR CONELE LMET LSRC

(d) Block 'CONSRC'

Contains precalculated source-dependant convective values for WCM and GAS

Routines found in:

CALXI SET CRISE CELE CONELE LSRC RECIND RISE

(e) Block 'CONST'

Contains constants used throughout METM, WCM, GAS and SHLINE

Routines found in:

METM MINIT HFLUX CON2 STB2 NEU2 CALXI WCM SURFR INIT SET CONV CU
CLU FZL CRISE CSURF CELE NSUR NWIND NRISE NELE STABLE SRISE SSUR
SELE CONRI CONSUR CONELE GEOMN INITG LMET LSRC NEURI NEUSUR
NEUELE RISE RSRC ROTATE SHOREL EVAL STBRI STBSUR STBELE SHLINE

(f) Block 'EX'

Contains file existence flags for WCM and GAS

Routines found in:

SET CONV CU CLU CRISE CSURF CELE NSUR NWIND NRISE NELE STABLE
SRISE SSUR SELE FUNEXT FUNEXF GAS RUNEXF RUNEXT

(g) Block 'FILES'

Contains file unit numbers and names used in METM, WCM, and GAS

Routines found in:

METM MINIT WCM GFILES SDEP INIT SET CONV CU CLU CRISE CSURF CELE
NSUR NWIND NRISE NELE STABLE SRISE SSUR SELE AVGARR BWIDTH CONRI
CONSUR CONELE FUNEXT FUNEXF GAS GEOMN INF JDMAX LMET ERRWRT
LSRC MOVING NEURI NEUSUR NEUELE RECD RUNEXF RECG RISE RSRC
RUNEXT WIND STBRI STBSUR STBELE

(h) Block 'FUNC'

Contains function file contents for GAS

Routines found in:

FUNEXT FUNEXF GAS LMET PFUN RUNEXT

(i) Block 'LEN'

Contains some file record lengths for GAS

Routines found in:

GAS RUNEXF

(j) Block 'METMOD'

Contains miscellaneous values used in METM

Routines found in:

METM MINIT HFLUX CON2 STB2 NEU2

(k) Block 'METVAR'

Contains calculated and inputted meteorological information used in METM, WCM, GAS
and SHLINE

Routines found in:

METM MINIT CON2 STB2 NEU2 CALXI SDEP INIT SET CONV CU CLU FZL CRISE

ANOND CSURF CELE NEUTRAL NSUR NWIND NRISE NELE STABLE SRISE SSUR
STEX SELE CONRI CONSUR CONELE INITG LMET LSRC NEURI NEUSUR NEUELE
RECIND RECG RISE SHOREL EVAL STBRI STBSUR STBELE SHLINE

(l) Block 'NSMET'

Contains met-dependant precalculated values for neutral and stable cases for GAS

Routines found in:

LMET NEUSUR NEUELE STBSUR STBELE

(m) Block 'NSSRC'

Contains source-dependant precalculated values for neutral and stable cases for GAS

Routines found in:

LSRC NEUELE STBELE

(n) Block 'PREC'

Contains wake and initial spread data, and elevated and error flags for WCM and GAS

Routines found in:

WCM SDEP CONV CU CLU CRISE CSURF CELE NEUTRAL NSUR NWIND NRISE
NELE STABLE SRISE SSUR SELE CONRI CONSUR CONELE LSRC NEURI NEUSUR
NEUELE RECD RECIND RECG RISE STBRI STBSUR STBELE

(o) Block 'RECEP'

Contains receptor data for GAS

Routines found in:

ARRMAX AVGARR GEOMN JDMAX LMET LSRC MOVING RECG WIND

(p) Block 'RISDAT'

Contains computed rise parameters for WCM, GAS and SHLINE

Routines found in:

SET CU CRISE CSURF NEUTRAL NWIND NRISE NELE STABLE SRISE SSUR STEX
SELE CONRI CONSUR LSRC NEURI NEUELE RECD RECIND RISE SHOREL STBRI
STBSUR STBELE SHLINE

(q) Block 'SHCNST'

Contains constants for shoreline routines for GAS and SHLINE

Routines found in:

SHOREL EVAL

(r) Block 'SHRPRE'

Contains precalculated values for shoreline routines for GAS and SHLINE

Routines found in:
SHOREL EVAL

(s) Block 'SHRVAR'

Contains shoreline data supplied to shoreline routines for GAS and SHLINE

Routines found in:
CONRI LMET RECIND RECG SHOREL EVAL SHLINE

(t) Block 'SOURCE'

Contains the current source's parameters for WCM and GAS and SHLINE

Routines found in:
CALXI SDEP SET CONV CU CRISE CSURF NEUTRAL NWIND NRISE NELE
STABLE SRISE SSUR STEX SELE CONRI CONELE LSRC NEURI NEUELE RECD
RECIND RECG RISE SHOREL EVAL STBRI STBELE SHLINE

(u) Block 'SPEC'D'

Contains special receptor information for GAS

Routines found in:
LMET RECG SPEC

(v) Block 'SRCARR'

Contains precalculated source-dependant data for all source for Routines found in:
LSRC RECIND

(w) Block 'SRCINF'

Contains parameters for all sources inputted for GAS and SHLINE

Routines found in:
BWIDTH CONRI LSRC RECD RECIND RECG RSRC WIND SHOREL EVAL LMET
SHLINE

(x) Block 'WHOLD'

Contains intermediate output results for WCM

Routines found in:
WCM RPRINT CONV CU CSURF CELE NEUTRAL NWIND STABLE SSUR STEX

(y) Block 'WLOOP'

Contains intermediate looping results for WCM

Routines found in:
SDEP SET CONV CU CLU CRISE CSURF CELE NEUTRAL NSUR NWIND NELE
STABLE SSUR STEX SELE

(z) Block 'WMISC'

Contains miscellaneous values for WCM

Routines found in:

SDEP SET CONV CLU CRISE CSURF CELE NEUTRAL NSUR NWIND NRISE NELE
STABLE SRISE SSUR SELE

Appendix G

APPENDIX G: Porting and Recompiling the Source Code

The code is written in Microsoft FORTRAN 77 Version 4.1. It is linked using the Microsoft Segmented-Executable Linker Version 5.01.20 to the library LLIBFORE (i.e. large memory model, inline floating point calls with emulator). The non-coprocessor code is linked to LLIBFORA (large memory model, alternate math calls).

To retrieve the source code for floppy disk based systems: prepare 2 blank formatted disks, insert the release diskette #1 in drive A and type:

```
A:\GETCODEF
```

then follow the instructions.

To retrieve the source code for hard disk based systems, insert the release diskette #1 in drive A and type:

```
A:\GETCODEH
```

then follow the instructions. The code will be placed in directory C:\CAP\SCODE.

Appendices E (Routine Calling Structures) and F (Common Blocks) may assist you in porting the code.

The code is not compatible with some compilers, among them: FORTRAN 66, Extended H FORTRAN and FORTRAN 5.

Only minor modifications will likely be necessary for most FORTRAN 77 compilers. Pay particular attention to the common block INCLUDE statements and the input and output statements (e.g. OPEN, and the use of the '\ ' control character). All names have been kept to no more than 6 characters for the sake of portability.

Porting WCM to another machine may present some problems, as it uses non-printable ASCII characters and ANSI.SYS calls for screen I/O. If ported, it should be used in file I/O mode only.

Appendix H

APPENDIX H: Troubleshooting Guide

- Q: "I try to execute a CAP menu option on my hard disk and get an error message 'Bad command or file name'."
- A: Check that the programs were installed correctly on your hard disk. You may have filled your disk and, as a result, some of the programs did not get installed. If this is the problem, it would appear as an 'Insufficient disk space' error during installation. Free up enough space on your hard disk and re-install the programs.
- Q: "I tried to run WCM but I got a lot of 'J23;43' type symbols along the left hand edge of the screen."
- A: You have not set up your CONFIG.SYS file correctly. See Section 2.2(h). Be sure to re-boot the computer after modifying CONFIG.SYS.
- Q: "I specified a receptor file in a RUN file, but GAS seemed to use its own."
- A: You probably specified a Straight Downwind Maximum Run. In order to use your own receptor file, you must reply 'N' to the request for a straight downwind maximum run (or use 0 meters for the minimum downwind search distance).
- Q: "I was running a program when it suddenly stopped with an 'Out of File Handles' error."
- A: Increase the number of FILES in the CONFIG.SYS file. See section 2.2(h).
- Q: "I was running a program when it suddenly stopped with an error trying to open a file."
- A: This can be due to a number of problems. Check that: i) you have enough file handles (section 2.2(h)). ii) if the output was directed to a floppy diskette check that the write protect tab is not present. iii) check that the output is not being directed to a disk that is full or nearly full (use the DOS DIR command to check free space). iv) insure that all required input files exist. v) insure that all filenames are legal and that all referenced directories exist.
- Q: "GAS wants me to create one or more files and then try my run again. What do I do?"
- A: Make a list of the files to create and use FM (appendix A) and the Record Layout section (appendix D) to create the files.

Q: "I am using FM to create a file but am not sure what to put in some of the fields."
A: Check the appropriate entry in the Record Layout section (appendix D). Pay particular attention to any notes at the bottom of the record layout.

Q: "FM won't let me edit a file."
A: This can be due to a number of problems. i) FM cannot find its associated files. Insure that installation proceeded correctly (i.e. no 'Insufficient disk space' error) and re-install the programs if necessary. ii) You are trying to run FM from a hard disk that sees the program as residing in other than C drive. Insure that FM is seen as being in C drive. iii) You are trying to edit a file with a non-supported extension (see appendix A.2(c)). iv) You have misspelled the filename extension.

Q: "FM displays a file's record all jumbled up, but when I use the DOS TYPE command, the file appears to be OK."
A: This problem can be due: i) having TAB characters in place of blanks. To eliminate TAB's, use a text editor that allows TAB to blank expansion. ii) not having fixed record lengths. To fix the record length, insure that each record is the correct size (appendix D) and that the last column in each record has a non-blank character. iii) the file has fields in the wrong locations. Check the Record Layout (appendix D).

Q: "The program will not run at all, not even to the point of printing a 'CAP Small-Scale Model' message immediately after execution."
A: You may not have enough main memory (512 K) or your PC may be insufficiently compatible.

Q: "I used the Print Screen key to print out the WCM screen display, but the boxes don't look the same."
A: Your printer is using a different character set than your PC. This will only make a cosmetic difference, but you may want to consult your printer manual for instructions on loading the PC character set.

APPENDIX 8-5

SUPPLEMENTARY CONTROL PROGRAMS

SUPPLEMENTARY CONTROL PROGRAMS

Existing Programs

Supplementary Control Programs (SCP) are currently operated in Ontario under special regulations, control orders and approvals. Examples of such control systems for sulphur dioxide are those operated by Ontario Hydro at their coal-fired stations at Sarnia and Lakeview, by the Lambton Industrial Society for the entire petrochemical complex in the Sarnia area, by Inco and Falconbridge in Sudbury, and by Algoma Steel in Wawa. In addition, the Air Pollution Index, a sub-index of the Province's new Air Quality Index system now operational in over 30 urban centres, is connected to a number of control programs which provide for pre-authorized cutbacks in emissions in the event of values exceeding critical levels.

Existing SCPs were established in the areas mentioned above because under certain meteorological conditions, the affected airsheds were not in compliance with either the current half-hour point of impingement standards or the ambient air quality criteria for SO₂. The conceptual basis for allowing the use of intermittent or supplementary control through production, and hence, emission curtailment or fuel switching was as an abatement tool for existing sources in non-compliance rather than for new operation.

In most instances, these programs were quite successful in significantly reducing the frequency of occurrence of excessive groundlevel concentrations of sulphur dioxide.

SCPs under Clean Air Program

Under the Clean Air Program the Ministry recognizes the need for SCPs as part of a non-attainment interim remedial strategy for airshed management in specific areas. In terms of the requirements to upgrade technology before SCPs are permitted, the Ministry will not allow supplementary controls as a substitute for bottom-of-the-stack controls. Subject to Ministry approval, supplementary controls will be permitted after the implementation of bottom-of-the-stack controls as follows:

For new sources, SCPs will be considered by the Ministry only for Level 3 contaminants if the proponent combines supplementary controls with Level 2 or Level 1 emission control technology.

For existing sources, currently not using supplementary controls, proposal for SCPs will be considered by the Ministry for Level 3 contaminants if the proponent combines such controls with Level 2 or Level 1 technology. For existing sources currently under SCPs, all of which are SO₂ emitters, the Ministry will allow their use, but will require the use of Level 1 control technology and compliance with the SO₂ air quality standard after a phase-in period.

Supplementary controls will not be allowed for facilities emitting Level 1 contaminants, in keeping with the thrust to virtually eliminate these emissions.

Supplementary Control Program Plan

The proponent must submit a proposal to the Ministry detailing how the supplementary control program would operate and show that this plan would result in compliance with air quality standards. The following elements must be incorporated in a supplementary control program:

- (a) Continuous emissions monitoring, or an accepted equivalent, of the contaminant(s) of concern.
- (b) An ambient air monitoring network, including perhaps mobile monitoring, to measure the groundlevel concentrations of the contaminant(s) of concern in the affected airshed; part or all of this network shall be owned and operated by the emitter(s); this network will incorporate "real-time" monitoring so as to provide feedback information to the emitters' central control room facilities for implementing emission reductions as required. The requirements for ambient air monitoring are described in Appendix 8.
- (c) A component to receive "real-time" weather data and weather prediction information which would be used along with dispersion modelling to anticipate potential conditions which could result in exceedences of air quality standards. Proponents must demonstrate

that their emission reductions would be of sufficient size and would be implemented in time to prevent exceedences in air quality standards. The dispersion modelling used in this assessment must be documented and must include possible influences of topography and other emission sources. Emission reduction strategies should look at the range of likely meteorological conditions for the forecast time period.

(d) An operations/procedures manual detailing the operations of the SCP, staff training requirements, hardware and software components of the data collection and reporting system, etc. The proponent shall submit this manual to the Ministry for approval, and update it as required.

An important aspect of a SCP is the need for high percent valid collection of "real-time" emissions and ambient monitoring information; hence, adequate monitoring and data processing instrumentation is required either as spare components or duplicates. These requirements are described in Appendices 9 and 10-1.

Program Reviews:

Since supplementary controls are not intended, in the long-term, to substitute for bottom-of-the-stack controls where these are technologically available, emitters using SCPs will be required, as a condition of approval, to review and justify their program needs to the Ministry every five years. In instances where the Ministry is of the opinion that the level of control technology required to meet the air quality standard(s) at all times has become available, the use of a SCP will be discontinued.

APPENDIX 9

SOURCE TESTING

A. General Provisions

All stationary sources of airborne contaminants, except those specifically exempted under other provisions outlined in this regulation will conduct source testing and/or install continuous emission monitors to determine compliance with process emission limits and/or compliance with conditions of certificates of approval.

Notwithstanding the provisions or requirements of any certificate of approval, the Ministry, at its discretion, may conduct source tests to determine compliance with emission limits; and through dispersion modelling, the air quality standards in Appendix 6. When the Ministry undertakes to conduct the tests, it shall provide reasonable notice to enable the proponent time to provide facilities described in Section B below.

Source testing, continuous emission monitors and/or an acceptable equivalent method of determining emissions (where permitted under other sections of this Appendix), are required on all point sources of contamination within a proponent's source complex including: stacks, vents, chimneys, flares and cooling towers. The testing, monitoring and/or equivalent method requirements also apply to line, volume or area sources including, but not restricted to: conveyor belts, tailings, storage piles, evaporation from ponds, leaks from valves, pipes, building doorways or windows, as well as all loading and unloading operations. Several of these latter source types are commonly referred to as "fugitive sources".

Sources of Level 1 and Level 2 contaminants (see Appendix 6-4) that require Lowest Available Emission Rate (LAER) control technology and Best Available Control Technology (BACT), respectively, must be continuously monitored. Specific contaminants, surrogate contaminants, operating conditions and/or maintenance of emission controls must be measured. Further details on continuous emission monitors are provided in Section C, below.

Sources of Level 3 contaminants may, at the discretion of the Ministry, be verified by methods other than stack testing where such methods result in a characterization of the emissions that is as good or better than conventional source tests with respect to accuracy and precision.

B. Source Testing - Specific Requirements

1. As part of an application for a certificate of approval, operators of existing non-mobile sources of Level 1, 2 or 3 air contaminants, unless otherwise exempted, will submit to the Ministry for approval, a detailed source testing plan.

This plan shall contain the following elements:

(a) **Site Plans and Equipment Specifications**

The testing plan will include a site plan showing the locations of all emission points, stack heights, stack radii and dimensions of all buildings or major obstructions on the site. The plan will include also dimensions of area or line sources; and the location and nature of all fugitive emissions.

(b) **Proposed Source Test Methods**

To assist proponents and those acting under contract to them, the Ministry has provided a source testing code (Subappendix 9-1) containing general testing methodologies. In addition, a schedule of recommended process or compound-specific testing methodologies, as developed in other jurisdictions, is provided (Subappendix 9-2). These Appendices will be updated from time to time as methods are developed that better characterize emissions.

Notwithstanding these appendices, proponents may, at their discretion, propose the use of alternate methodologies. In the event that such alternate methods are used, proponents must demonstrate to the satisfaction of the Ministry that such alternate methodologies will characterize emissions, with respect to accuracy and precision, as well or better than those methods recommended in Subappendices 9-1 and 9-2.

- (c) Operating conditions during the source testing
The plan will include all information (on process operating capacity and conditions) needed to demonstrate to the satisfaction of the Ministry that the source tests will be conducted while the source(s) of air contaminant is (are) operating at maximum routine operating conditions.
- 2. All proponents of new facilities, or those wishing to modify existing facilities, are required to provide, as part of their application for a certificate of approval (to Operate), a source testing plan that includes all information listed above in B.1 (a),(b), and (c).
- 3. A contaminant or contaminants may be excluded from the testing program based on the small source exemptions described in Appendix 5. Such exemptions are based on the toxicity of the compound or element as determined by the Ministry, and, the amount of such compound or element emitted per unit time. The onus is on proponents to prove, through appropriate calculations, that the contaminant should be excluded from the testing program.
- 4. Post-start-up source testing will be conducted within time limits specified in certificates of approval. Proponents will give at least 30 days prior notice to the Ministry of the specific date(s), time(s) and location(s) that such tests will be conducted and will conduct the tests according to the submitted test plan or such plan as modified by the Ministry.
- 5. Proponents will permit access to their facilities for Ministry staff or their designees, to witness such source tests. Whether the Ministry itself conducts the tests, or witnesses the conduct of the tests by others, proponents shall provide the following:
 - (a) sampling ports adequate for the applicable test methods for each source;
 - (b) safe sampling platforms;
 - (c) safe access to these sampling platforms; and

- (d) other essential equipment needed to conduct successful tests such as enclosures for testing during inclement weather.

When the Ministry conducts the tests, proponents shall also provide utilities for the sampling and testing equipment.

- 6. All source testing must be conducted and the reports prepared in accordance with the provisions outlined in the Source Testing Code (Subappendix 9-1). All laboratory analyses associated with source testing must be carried out in a Canadian Standards Association (CSA) accredited laboratory.
- 7. Source test data will be reported to the Ministry in a format as defined in the Source Testing Code (Subappendix 9-1).
- 8. Source testing will be repeated as required by certificates of approval or, as required by the Ministry.

C. Continuous Emission Monitoring

- 1. The Ministry will require all new or modified sources listed in Table 1, attached, to install continuous emission monitoring systems (CEMS) for designated pollutants and/or designated operating parameters.
- 2. All CEMS installed to meet the requirements of Section 1 above will comply with the Performance Specifications of Table 2, including the relative accuracy specifications which must be demonstrated by comparison with measurements performed according to the methods listed in Subappendices 9-1 ("Source Testing Code") or 9-2 ("Source Testing Methodologies from Other Jurisdictions").
- 3. All CEMS installed to meet the requirements of section B.1 will be calibrated daily with reference materials and methods approved by the

Ministry. In addition, the entire CEMS must be audited quarter annually using reference materials and methods approved by the Ministry.

4. All CEMS installed to meet the requirements of section B.1 shall be provided with an operation and maintenance manual which shall be submitted to the Ministry for approval, and which shall be revised and/or updated regularly by the source operator. The manual shall include a list of necessary spare parts, estimated budget and maintenance staff allocations, and a CEMS operator training plan.
5. All CEMS installed to meet the requirements of section B.1 shall be operated and maintained according to the manual cited in section B.4, so that accurate data are obtained during a minimum of 90 percent of the time in which the source associated process is in operation. This target shall be met on a monthly basis.
6. All CEMS installed to meet the requirements of section B.1 shall maintain for a minimum of two years the records of all measurements, calibrations and maintenance. The operator of the source must report to the Ministry quarterly, in a format approved by the Ministry, a summary of the CEMS measurements, including calibrations and audit.
7. The Ministry may require any new or modified source of Levels 1 or 2 contaminants to install CEMS for the Level 1 or 2 contaminant, or for a designated surrogate compound, or for a designated process parameter. These CEMS shall be subject to requirements equivalent to those in sections B.2 to B.6.
8. The Ministry will require any existing source listed in Table 1, or any existing source of Level 1 or 2 contaminants, to install CEMS for the designated pollutants, for the Level 1 or 2 pollutant, or for a designated surrogate compound, or for a designated process parameter. These CEMS shall be subject to the requirements equivalent to those in sections B.2 to B.6 above.

D. Alternatives to Source Testing

Proponents may include in a source test plan, the use of alternative methods to quantify emissions of Level 3 contaminants.

Alternative methods may be used also to quantify emissions from fugitive sources. Such emissions might be calculated from physical measurements such as storage pile dimensions, by portable contaminant detection devices often used in industrial hygiene monitoring applications, or other available technical guidance as needed.

Regardless of the alternative method used, proponents must prove to the Ministry's satisfaction that the alternative method will result in as good or better characterization of the emissions, with respect to accuracy and precision, than a conventional source test.

E. Pooled Source Testing

Pooled testing refers to any technique which permits companies or groups of companies to gather data on emission points which are similar in nature, within their complexes, without the added and unnecessary expense of source testing (or continuously monitoring) every point.

The operators/owners of a group of related facilities may propose in each of their respective source testing plans, to satisfy any source testing requirement by performing a limited number of representative source tests and applying the results to each of their respective facilities. These proposals shall be submitted for review by the Ministry as part of a consolidated proposal during application(s) for certificates of approval. Such applications will normally require the cooperation of the owners of the similar sources through trade associations.

Such pooled tests will result in specific conditions on the certificates of approval of the pooled sources that in themselves will be enforceable, such as operating temperatures, flow rates, retention times, etc.

The Ministry will approve the proposal for inclusion in the certificates of approval of participating facilities which were not source tested, but to which the results are proposed to be applied only if;

- (1) the facility operator includes in the plan sufficient information regarding operating conditions, input and output streams, equipment characteristics, control equipment, and other parameters affecting emission characteristics to enable the Ministry to make a determination that sufficient similarity in all parameters affecting emissions of listed substances exists between the facility tested and the facility to which the results are proposed to be applied, such that emissions can be calculated to yield representative emission results to the required degree of accuracy; and,
- (2) if applicable, the facility operator corrects all deficiencies identified by the Ministry.

If the proposal is not approved by the Ministry, each facility shall undertake individual source testing programs, as required.

Table 1: CEMS Requirements for Designated Sources

EMISSION SOURCE	M O N I T O R I N G EQUIPMENT
Coal and/or Oil Fired Boilers of >73MW heat input rate	Opacity SO ₂ NO O ₂ or CO ₂
Gas Fired Boilers of >73 MW heat input rate	NO O ₂ or CO ₂
Nitric Acid Plants (Process equipment)	NOx
Sulphuric Acid Plants (Process equipment)	SO ₂
Petroleum Refineries	
FCC catalyst regenerator	Opacity CO
Fuel Gas Combustion Device	H ₂ S
Claus Recovery Unit with Incinerator	SO ₂
Reduction Control System without incin.	H ₂ S
Primary Copper Smelters	
Dryer	Opacity
Roaster	SO ₂
Primary Zinc Smelters	
Sintering Machine	Opacity
Roaster	SO ₂
Ferroalloy Production Facility	
Electric submerged arc furnace	Opacity

Table 1 continued:

EMISSION SOURCE	MONITORING REQUIREMENT
Iron and Steel Plants	
Electric arc furnace control device	Opacity
Kraft Pulp Mills	
Recovery Furnace	Opacity
Lime Kilns	TRS
Portland Cement	
Kilns	Opacity
Clinker Coolers	Opacity
Municipal Waste Incinerators	Opacity CO or THC O ₂ NO SO ₂ Furn. Temp.
Biomedical Waste Incinerators	Opacity CO or THC Secondary Chamber Temperature

TABLE 2: CEMS Performance Requirements

(CEMS performance requirements for opacity, SO₂, NO_x, O₂, CO₂, CO, TRS and Flow are available from the USA EPA, 40 CFR, Part 60)

APPENDIX 9-1

SOURCE TESTING CODE

The Source Testing Code which is available through the Air Resources Branch library will require a number of changes prior to promulgation of the Clean Air Program:

- (a) changes to the "Introduction" and that section titled "Conducting a Source Sampling Test", to clarify the qualifications of those conducting source testing and/or authorizing the test reports. This might include a requirement that Source Test reports be certified correct by a Professional Engineer, who is a member in good standing of the Association of Professional Engineers of Ontario;
- (b) a section on data reduction and the reporting format of source testing data for submission to the Ministry; and possibly, as an aid to industry,
- (c) a section on acceptable alternate methods of estimating emissions without conducting formal source tests.

APPENDIX 9-2

SOURCE TESTING METHODOLOGIES IN OTHER JURISDICTIONS

SOURCE TESTING: Methodologies from Other Jurisdictions

The following U.S. Federal Reference Test Methods, described in Code of Federal Regulations (C.F.R.) 40, part 60, July 1, 1989 or later revisions are reference test methods required under this schedule:

Method Stationary Source Sampling Method

- 1 Sample and velocity traverses for stationary sources
- 1A Sample and velocity traverses for stationary sources with small stacks or ducts
- 2 Determination of stack gas velocity and volumetric flow rate (type s pitot tube)
- 2A Direct measurement of gas volume through pipes and small ducts
- 2B Determination of exhaust gas volume flow rate from gasoline vapour incinerators
- 2C Determination of stack gas velocity and volumetric flow rate from small stacks or duct (standard pitot tube)
- 2D Measurement of gas volume flow rate in small pipes and ducts
- 3 Gas analysis for carbon dioxide, excess air, and dry molecular weight
- 4 Determination of moisture content in stack gases
- 5 Determination of particulate emissions from stationary sources
- 5A Determination of particulate emissions from the asphalt processing and asphalt roofing industry
- 5B Determination of nonsulfuric acid particulate matter from electric utility steam generators
- 5C Determination of particulate emissions from stationary sources with small stacks or ducts
- 5D Determination of particulate matter emissions from positive pressure fabric filters
- 5E Determination of particulate emissions from wool fibreglass insulation manufacturing industry

- 5F Determination of nonsulfate particulate matter from stationary sources
- 6 Determination of sulfur dioxide emissions from stationary sources
- 6A Determination of sulfur dioxide and carbon dioxide emissions from fossil fuel combustion sources
- 6B Determination of sulfur dioxide and carbon dioxide daily average emissions from fossil fuel combustion sources
- 7 Determination of nitrogen oxide emissions from stationary sources
- 7A Determination of nitrogen oxide emissions from stationary sources: iron chromatographic method
- 7B Determination of nitrogen oxide emissions from stationary sources : ultraviolet spectrophotometry
- 7C Determination of nitrogen oxide emissions from stationary sources : alkaline-permanganate\colorimetric method
- 8 Determination of sulfuric acid mist and sulfur dioxide emissions from stationary sources
- 9 Visual determination of opacity of emissions from stationary sources
- 9A Alternate 1-determination of the opacity of emissions of stationary sources remotely by lidar
- 10 Determination of carbon monoxide emissions from stationary sources
- 11 Determination of hydrogen sulfide emissions from stationary sources
- 12 Determination of inorganic lead emissions from stationary sources
- 13A Determination of total fluoride emissions from stationary sources - spadns zirconium lake method
- 13B Determination of total fluoride emissions from stationary sources - specific ion electrode method
- 14 Determination of fluoride emissions from potroom roof monitors
- 15 Determination of hydrogen sulfide, carbonyl sulfide, and carbon disulfide emissions from stationary sources

- 16 Semicontinuous determination of sulfur emissions from stationary sources
- 16A Determination of total reduced sulfur emissions from stationary sources
- 17 Determination of particulate emissions from stationary sources (in-stack filtration method)
- 18 Measurement of gaseous organic compound emissions by gas chromatography
- 19 Determination of sulfur dioxide removal efficiency and particulate ,sulfur dioxide and nitrogen oxides emission rates from electric utility stream generators
- 19A Determination of sulfur dioxide emission rates from fossil fuel-fired steam generators
- 20 Determination of nitrogen oxide, sulfur dioxide, and oxygen emissions from stationary gas turbines
- 21 Determination of volatile organic compounds leaks
- 22 Visual determination of fugitive emissions from material processing sources
- 23 Determination of polyhalogenated dibenzo-p-dioxins and polychlorinated dibenzo-furans from stationary sources
- 24 Determination of volatile matter content, water content, density, volume solids, and weight solids of surface coatings
- 24A Determination of volatile matter content and density of printing inks and related coatings
- 25 Determination of total gaseous organic concentration using a flame ionization analyzer
- 25B Determination of total gaseous organic concentration using a nondispersive infrared analyzer
- 27 Determination of vapour tightness of gaseous delivery tank using pressure-vacuum test
- 30 Determination of volatile organic matter content using VOST (draft to be promulgated)
- 101 Determination of particulate and gaseous mercury emissions from chlor-alkali plants -air streams

- 101A Determination of particulate and gaseous mercury emissions from sewage sludge incinerators
- 102 Determination of particulate and gaseous mercury emissions from chlo-alkali plants -hydrogen streams
- 103 Beryllium screening method
- 104 Reference method for determination of beryllium emissions from stationary sources
- 105 Method for determination of mercury in wastewater treatment plant sewage sludges
- 106 Determination of vinyl chloride from stationary sources
- 107 Determination of vinyl chloride content of inprocess wastewater samples, and vinyl chloride content of polyvinyl chloride resin, slurry, wet cake, and latex samples
- 107A Determination of vinyl chloride content of solvents, resin-solvent solution, polyvinyl chloride resin, resin slurry, wet resin, and latex samples
- 108 Determination of particulate and gaseous arsenic emission from non ferrous smelters
- 109 Determination of visible emissions from coke oven batteries
- 110 Determination of benzene from stationary sources
- 111 Determination of polonium -210 emissions from stationary sources

In addition to the preceding, the following method is recommended for formaldehyde: Colorimetric method using 2,4 Dinitrophenylhydrazone, (J. P. Lodge, Methods of Air Sampling and Analysis, 1989, page 293).

APPENDIX 10

AMBIENT AIR MONITORING

GENERAL REQUIREMENTS

- A. As part of the approval process for new sources, pre-operational, background air concentrations will be required, to assess the air quality impact of the proposed source. Such concentrations can be determined from either mathematical modelling (see Appendix 8) or monitoring. Background data may be acquired from the Ministry of the Environment in certain cases, or may require a pre-operational monitoring survey by the proponent. If monitoring is carried out to determine background concentrations, then procedures detailed in section F below should be followed, and the particular monitored value to be used as "background" for the modelling work detailed in Appendix 8 will be determined in the following manner. If the appropriate sample collection period is equal to or less than 24 hours, use the second - highest measured value determined over the period of one year. If the appropriate collection period is longer than 24 hours (e.g. monthly or seasonal), then use the maximum measured value over the period of one year.
- B. Cases where site - specific, pre-operational monitoring are required of a proponent will be identified as part of the approval process. Pre-operational monitoring may be required if:
1. No monitoring data are available for the location in question, and reasonable modelling estimates of pre-operational ambient levels are not possible;
 2. There are special local emission or dispersion problems for the specific area under consideration (e.g. street canyon effects); or,
- Pre-operational ambient monitoring will be required of, but not limited to, waste incinerators, primary metallurgical plants and steel making facilities.
- C. In certain cases, receptor monitoring may also be required of the proponent. Examples of "receptor monitoring" include vegetation, soil or snow sampling, to determine the levels of target compounds in the receptor prior to, and after, the

onset of operations. Procedures for receptor monitoring are detailed in the attached Subappendix 10-2 entitled: "Assessing the impact of airborne contaminants on soil and terrestrial vegetation".

D. Source-oriented post-startup monitoring (air and/or receptor) will be required of the proponent in the following two circumstances.

1. Continuous ambient air monitoring in the vicinity of the source complex will be required if a proponent makes use of supplementary control programs (i.e. cutting emissions under adverse meteorological conditions) to meet ambient air quality standards (see Appendix 8-5: "Supplementary Control Programs").
2. Pre-operational ambient monitoring will be required of, but not limited to, waste incinerators, primary metallurgical plants and steel making facilities.

E. Source-oriented post-startup monitoring may be required of the proponent in the following two circumstances.

1. Emissions from the proponent's source complex show a modelled maximum contribution of at least 10% of any appropriate air quality standard for contaminants classified as level 1.
2. Emissions from a combination of the proponent's source complex and all background sources show a modelled maximum contribution of at least 50% of the appropriate air quality standard for contaminants classified as level 2 or 3.

Both pre- and post-startup monitoring programs will have to span a minimum of one year, and yield results which are representative of the plant operating conditions as described in the certificate of approval for both the annual period and each season within the year.

F. Proponents required to carry out either pre -or post-startup monitoring will be required to submit for the Director's approval a survey plan at least three months prior to the proposed network installation date. This plan should include the following elements:

1. the time period covered by the proposed monitoring program;
2. the frequency of sample collection;

Note that the actual individual sample collection period for ambient air samples should be in conformity with the appropriate air quality standard for the substance(s) in question. Note also that the data should be collected in such a way as to yield representative seasonal and annual means.

3. the monitoring methods to be used;

Methods recommended by the Ministry are detailed in Subappendix 10-1, but equivalent methods, that is, those which have a comparable or better specificity, reproducibility and sensitivity for the target compounds or receptors under consideration, will be accepted. If Ministry methods are not available, then the proponent will provide a rationale for the method to be used.

4. the laboratory analysis methods to be used;

Methods recommended by the Ministry are detailed in Subappendix 10-1, but equivalent methods will be accepted. The laboratory analysis must be carried out by a Canadian Standards Association (CSA - accredited laboratory. If Ministry methods are not available, then the proponent will provide a rationale for the method to be used;

5. the overall detection limits of the proposed monitoring and analysis methods.

and the way in which these detection limits have been determined;

Note that for ambient air samples these overall detection limits should be no greater than one-tenth of the air quality standard.

6. the Quality Assurance/Quality Control program to be instituted, covering both field and laboratory operations as described in Appendix 11;

7. a description of the database to be used for the results;

The database should be compatible with the Ministry's requirements, as published from time to time.

8. a description of how the data will be used to assess compliance with the Ministry's air quality standards; and,

9. a specification of the frequency of reporting the results, and the form of the reports.

- G. The proponent may have to submit the monitoring program to external audit. External audits may include inspection by Ministry or other designated (by the Ministry) experts of the on-site and laboratory facilities, requirements to participate in intercomparisons, parallel monitoring by the Ministry's Mobile Air Monitoring Units, monitor calibration by the Ministry's Air Quality and Meteorological Section or receptor monitoring surveys by the Ministry's Phytotoxicology Section (see also Subappendix 10-2 and Appendix 11).

APPENDIX 10-1

AMBIENT AIR MONITORING

APPROVED SAMPLING AND

ANALYTICAL METHODS

Introduction

This Appendix summarizes the sampling and analytical methods approved by the Ministry for pre-operational and post start-up ambient air monitoring. Where ambient monitoring of specified chemicals is required to comply with conditions of a certificate of approval, the appropriate sampling and analytical method is to be selected from the following Table 1: "Approved Sampling and Analytical Methods", attached. Applicable documentation is available from the sources indicated.

The Ministry will from time to time revise this Table, adding new, or revising existing methodologies as they are developed and become available for general use.

When Ministry-approved methods do not exist it is the responsibility of the proponent to recommend to the Ministry, acceptable sampling and analytical methods for the target contaminants.

TABLE 10.1 APPROVED SAMPLING AND ANALYTICAL METHODS.

POLLUTANT	SAMPLING METHOD	ANALYTICAL METHOD	DOCUMENTATION
Benzene	Carbon molecular sieve or SUMMA polished canister	GC-MS, GC-FID, or GC-Multi-detector (GC-FID-ECD-PID) system	<p>Ontario Ministry of the Environment, Report # ARB-224-89</p> <p>Ontario Ministry of the Environment, Laboratory Services Document # PATH123-E3131A</p> <p>U.S. EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Method TO-02 and TO-14</p>
Vinyl Chloride	Carbon molecular sieve or SUMMA polished canister	GC-MS, GC-FID, or GC-Multi-detector (GC-FID-ECD-PID) system	<p>Ontario Ministry of the Environment, Report # ARB-224-89</p> <p>Ontario Ministry of the Environment, Laboratory Services Document # PATH123-E3131A</p> <p>U.S. EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Method TO-02 and TO-14</p> <p>Canadian Standards Association Method for the Measurement of Vinyl Chloride in Air, CAN3-Z223.25-M86</p>
Lead	High volume sampler with glass or quartz fibre, cellulose or teflon filter	AAS, ICP-MS, INAA, XRF	<p>Ontario Ministry of the Environment, Report # AMP-101</p> <p>Ontario Ministry of the Environment, Laboratory Services Branch Document # HMHFHV-E3070A</p>
Dioxins/ Furans	Filter with polyurethane foam vapour trap	GC/MS/MS, HRGC/HRMS	<p>Ontario Ministry of the Environment, Report # ARB-225-89</p> <p>U.S. EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Method TO-09</p>
Formaldehyde	DNPH impinger	HPLC	<p>U.S. EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Method TO-05</p> <p>Ontario Ministry of the Environment, Report in preparation</p>

TABLE 10.1 APPROVED SAMPLING AND ANALYTICAL METHODS (Continued).

POLLUTANT	SAMPLING METHOD	ANALYTICAL METHOD	DOCUMENTATION
Carbon Tetrachloride	Carbon molecular sieve or SUMMA polished canister	GC-MS, GC-FID, or GC-Multi-detector (GC-FID-ECD-PID) system	Ontario Ministry of the Environment Report # ARB-224-89 Ontario Ministry of the Environment, Laboratory Services Document # PATH123-E3131A U.S. EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Method TO-02 and TO-14
Manganese	High or low volume sampler with glass or quartz fibre, cellulose or teflon filter	AAS, ICP-MS, INAA, XRF	Ontario Ministry of the Environment, Report # AMP-101 Ontario Ministry of the Environment, Laboratory Services Branch Document # HMHFHV-E3070A
Acrylonitrile	Carbon molecular sieve or <i>in situ</i> cryogenic preconcentration	GC-MS, GC-FID, GC-FID-ECD	Ontario Ministry of the Environment Report # ARB-224-89 Ontario Ministry of the Environment, Laboratory Services Document # PATH123-E3131A U.S. EPA Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Method TO-02 and TO-03

ABBREVIATIONS: GC	Gas Chromatography
MS	Mass Spectrometry
FID	Flame Ionization Detector
PID	Photo Ionization Detector
ECD	Electron Capture Detector
AAS	Atomic Absorption Spectrophotometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INAA	Instrumental Neutron Activation Analysis
XRF	X-ray Fluorescence Analysis
HPLC	High Pressure Liquid Chromatography
HRGC	High Resolution Gas Chromatography
HRMS	High Resolution Mass Spectrometry
DNPB	Dinitrophenylhydrazine

APPENDIX 10-2

ASSESSING THE IMPACT OF AIRBORNE CONTAMINANTS ON SOIL & TERRESTRIAL VEGETATION

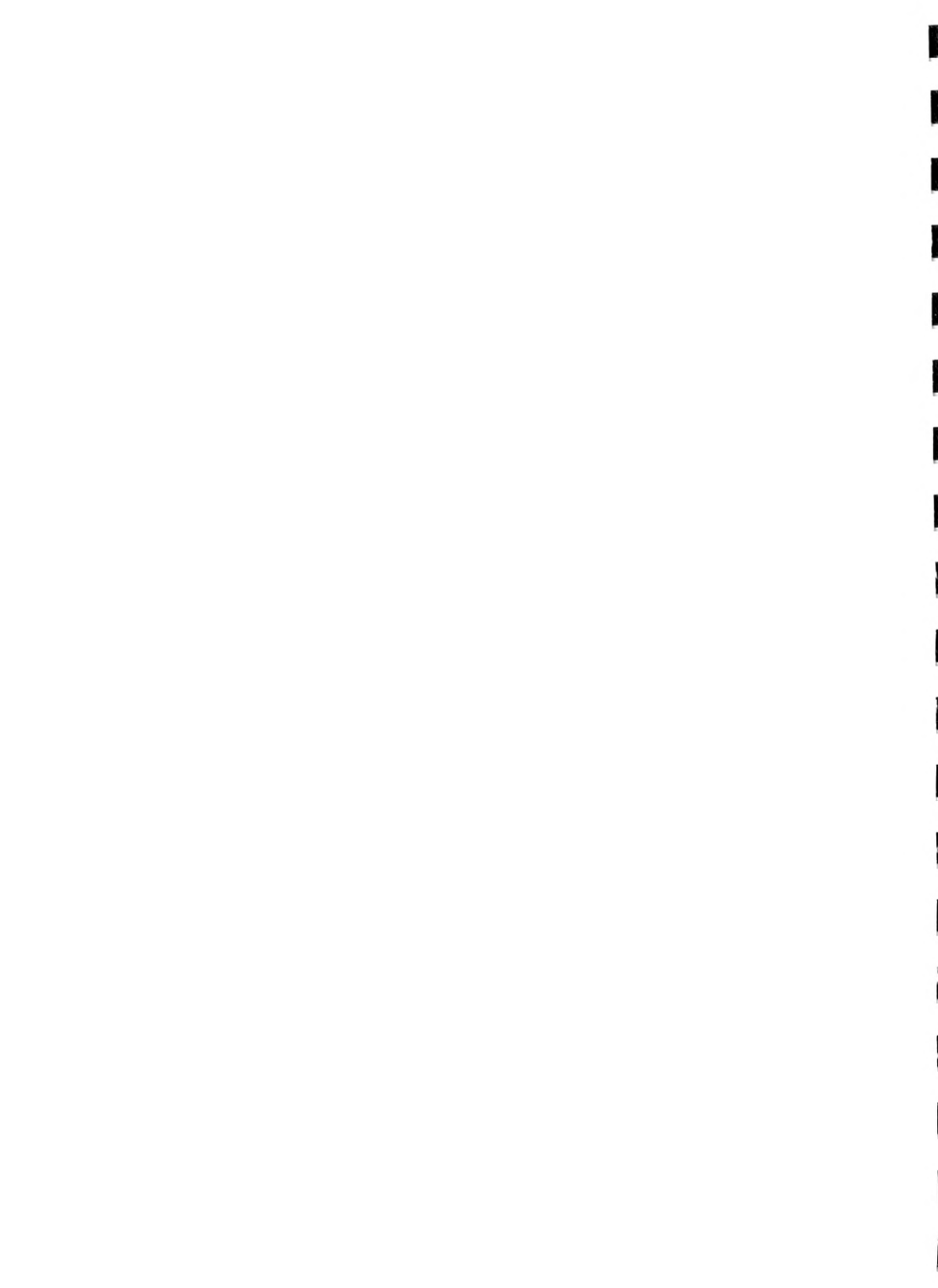


Table of Contents

1 PLANT RESPONSE TO AIR AND SOIL POLLUTANTS	1
1.1 Pollutant Induced Injury Symptoms	1
1.2 Mimicking Symptoms	2
1.3 Susceptibility Ratings	2
2 EVALUATION OF INJURY OR LOSS	3
2.1 Visible Injury Assessment	4
2.2 Yield and Growth Assessment	7
2.2.1 Seed Crops	7
2.2.2 Forage Crops	8
2.2.3 Vegetable Crops	8
2.2.4 Growth Parameters	8
2.2.5 Quality Parameters	13
2.2.6 Reproductive Potential	13
3 FIELD INVESTIGATION PROCEDURES	14
3.1 Vegetation Assessment Surveys	14
3.1.1 Survey Type or Emphasis	14
3.1.2 Survey Configuration or Layout	15
3.1.3 Species Selection	16
3.1.4 Survey Timing	17
3.1.5 Control Site Selection	17
3.2 Auxiliary Support Techniques	17
3.2.1 Indicator Plots	18
3.2.2 Moss Bag Ion Receptors	18
3.2.3 Bioassay Growth Studies	19
3.2.4 Leaf Litter Bags	21
4 SAMPLE COLLECTION PROCEDURES	22
4.1 Vegetation	22
4.1.1 Inorganic Chemical Analysis	22
4.1.1.1 Tree and Shrub Foliage	22
4.1.1.2 Forage	23
4.1.1.3 Garden Produce	24
4.1.2 Organic Chemical Analysis	24
4.1.3 Radioactivity	24
4.2 Soil	24
4.2.1 Inorganic Chemical Analysis	24
4.2.1.1 Total Levels	24
4.2.1.2 Plant available or Extractable Levels	25
4.2.2 Fertility	25
4.2.3 Lead in Residential Soils	25
4.2.3.1 General Sampling Guidelines	25
4.2.3.2 Site Selection	26
4.2.4 Conductivity Determinations	26
4.2.5 Organic Chemical Analysis	26
4.2.5.1 Avoidance of Cross-contamination	26

4.2.5.2 Equipment Cleaning Procedure	27
4.2.5.3 Sample Containers	27
4.2.5.4 Sample Preservation	27
4.2.6 Site Remediation or Decommissioning	27
4.2.6.1 Determination of Degree of Contamination	27
4.2.6.2 Post-clean-up Verification Sampling	28
4.2.6.2.1 Surface Sampling	28
4.2.6.2.2 Depth Sampling	28
4.2.7 Soil Radioactivity	29
4.3 Snow Sampling	29
4.3.1 Site Selection	29
4.3.2 Sample Collection	29
4.4 Sampling for Non-chemical Analysis Purposes	30
4.4.1 Pathology Diagnosis	30
4.4.2 Nematode Diagnosis	30
4.4.3 Insect Pest Diagnosis	30
4.4.4 Histology Diagnosis	32
4.4.5 Herbarium Preservation	33
5 LABORATORY METHODS	33
5.1 Sample Preparation	33
5.1.1 Vegetation Samples	33
5.1.1.1 Temporary preservation in the field	33
5.1.1.2 Transporting vegetation samples to the processing laboratory	33
5.1.1.3 Processing of Not-Washed Vegetation Samples	34
5.1.1.4 Processing of Washed Vegetation Samples	34
5.1.1.4.1 Washing Procedure	34
5.1.1.4.2 Preparation of Washing Solutions	34
5.1.1.4.3 Preparation of Alternative Soap Solutions - Sulphur Analysis ...	35
5.1.1.4.4 Distilled Water Washes	35
5.1.1.4.5 Dilute Acid Washing Solutions	35
5.1.1.4.6 Organic Solvent Washes	35
5.1.1.4.7 Preparation and Washing Edible Vegetables and Fruits	36
5.1.1.4.8 Grinding of Vegetation in the Wiley Mill	37
5.1.1.4.9 Grinding of Vegetation Using Liquid Nitrogen	38
5.1.2 Processing Soil Samples	39
5.1.2.1 Transporting of Soil Samples	39
5.1.2.2 Processing of Soil Samples for Chemical Analysis	39
5.1.2.3 Processing of Soil Samples for pH Determination	39
5.1.2.4 Processing of Soil Samples for pH Determination in CaCl ₂ Solution	40
5.1.2.5 Processing of Soil Samples for Conductivity Determination	40
5.1.2.6 Ammonium Acetate Extract Procedures for Soil	41
5.1.2.7 Hot Water Soluble Extract Procedure for Soil	41
5.1.2.8 Acid Extractable Metals from Soil	42
5.1.3 Processing Of Mossbag Monitors	42
5.1.4 Snow Samples	43
5.1.5 Miscellaneous Techniques	43
5.2 Suggested Analytical Methods	44

6 INTERPRETATION OF ANALYTICAL RESULTS	44
6.1 Upper Limit of Normal Contaminant Guidelines - Derivation and Significance	44
6.2 Soil Conductivity	45

1 PLANT RESPONSE TO AIR AND SOIL POLLUTANTS

1.1 Pollutant Induced Injury Symptoms

By careful observation of an injured plants, it is usually possible to differentiate between the symptoms induced by a pollutant and those associated with a host of other biological agents or environmental factors. In general, the primary concern is with those pollutants in the gaseous phase as these enter the leaf through the stomata; however, there are many other contaminants which can cause injury through deposition in liquid, aerosol or solid (particulate) phase, or via uptake from contaminated soil. The following table describes in a very generalized manner the common symptom types for ten of the common pollutants which are encountered in Ontario.

Table 1: Typical Injury Symptoms of Ten Common Pollutants

Pollutant	Typical Acute Foliar Injury Symptoms
Ammonia	Initially leaves display cooked green appearance. Broadleaf tissues collapse to form irregular dark or discoloured marginal or interveinal areas, whereas grasses often show reddish, interveinal necrotic streaking or dark upper surface discoloration.
Arsenic	Predominantly marginal necrosis varying from light tan to brown-black in color. On Manitoba and silver maple the leaf margins tend to curl inwards.
Boron	Most common symptoms include irregular dark intercostal necrosis lesions with occasional marginal necrosis, severe leaf distortion, and twig dieback; leaves frequently have a desiccated or burned appearance.
Chlorine	Can mimic other air pollutants (SO ₂ , O ₃). Intercostal chlorosis and necrosis followed by bleaching of necrotic tissue. Silvering of upper leaf surface has been noted.
Fluoride	Injury is primarily tip and marginal. Necrotic areas are often reddish-brown, separated from healthy areas by a sharply-defined band; e.g. apricot, plum, white pine. Necrotic areas occasionally blackened; e.g. silver maple. Monocot leaves show streaked or banded necrotic areas; e.g. sweet corn.

Mercury	General chlorosis of leaf. At high concentrations, brown spotting on leaves; flower parts, blacken; e.g. rose, carnation.
Nitrogen dioxide	Similar to SO ₂ . Large irregular water-soaked areas later bleach to a brown or tan color. Lesions are mainly intercostal; e.g. tobacco, pinto bean, hibiscus.
Ozone	Small irregular fleck or stipple-like lesions on upper leaf surface; can be light or dark; lesions often collapse, giving pitted appearance to leaf; e.g. tobacco, ash, grape. Coniferous needles show stipple-like chlorotic spots; e.g. white pine.
Sodium chloride	Marginal or tip necrosis. Trees may have "witches broom" appearance due to twig dieback. Injury near salted highways is generally one-sided.
Sulphur dioxide	Woody plants; brown or reddish-brown intercostal necrosis; small to large irregularly-shaped lesions. Herbs: marginal or intercostal necrosis; necrotic areas bleach to ivory or tan color. e.g. alfalfa, buckwheat.

Numerous summaries of pollutant injury descriptions have been published during the past thirty years. Some at least of these are available in most institutional libraries.

1.2 Mimicking Symptoms

Various stress including nutrient deficiencies and extreme temperature can induce injury symptoms that mimic air pollution symptoms. Several of the references referred to above include descriptions of mimicking symptoms.

1.3 Susceptibility Ratings

Plant species do not respond identically to air pollutants. For each known phytotoxic pollutant there are plant species (and cultivars within species) which are sensitive; another group of species and cultivars which are tolerant and a number of species between these extremes which are considered intermediate in their sensitivity to that pollutant. (In practice it is best to consider the spectrum of plant response a continuum). A knowledge of this differential response

to various pollutants is often a useful diagnostic tool; and, in cases where symptomatology can be confusing and tissue analysis often futile, such as chlorine injury, the use of differential sensitivity is indispensable.

Plant susceptibility ratings for the most common and best documented air pollutants (hydrogen fluoride, ozone, sulphur dioxide, ammonia, hydrogen chloride and chlorine) are presented in a bar graph form in the Phytotoxicology Field Investigation Manual (ARB-xxx-89-PHYTO). Susceptibilities of some species to landfill gases are also given. The position of each bar with respect to the three headings (sensitive, intermediate and tolerant) establishes the sensitivity of that plant species or cultivar to the pollutant; the length of each bar is a measure of the variability of that species.

Various other plant sensitivity listings are available in scientific publications utilizing different forms of expression.

2 EVALUATION OF INJURY OR LOSS

Evaluation of the extent of air and/or soil contaminant effects on vegetation is central to the interpretation of overall losses to pollution. To be effective, the evaluation of these effects must be objective, accurate and standardized.

It is beyond the scope of the present chapter to place an economic value on the injury to vegetation or even to provide a means of determining this value. Vegetation may suffer many types of injury due to exposure to various pollutants. Some injury may be readily visible while other types of injury may be difficult to assess.

Injury to vegetation may be considered as a loss in yield (i.e. reduced biomass, reduction of seed crop, etc.), loss in quality (i.e. fleck in tobacco, injury to edible foliage, lowered nutrient content), increased toxicity (Eg. fluoride in forage) or as decrease in aesthetic value (i.e. colour change of foliage, lowered production of flowers, loss of species from the ecosystem).

The present chapter will serve primarily as a guide to the evaluation of visible injury and yield and growth parameters.

2.1 Visible Injury Assessment

The accuracy of the assessment of visible injury is directly dependent on the technique used to evaluate the injury. It should be self-evident that plants examined by any sampling technique should be representative of the plant present in the crop (or specified area) under investigation.

In an evaluation of injury, the severity of injury can be evaluated on the basis of:

1. Average percentage of leaf area affected on an entire plant or tree basis.
2. Average percentage of leaf area affected on a sample basis.
3. Percentage (and location) of leaves affected on a plant.
4. Percentage of affected plants in a designated area.

Regardless of the system employed it is imperative that the basis for evaluation be clearly stated.

1. Numerical
2. Relative severity
3. Percentage values

Various numerical rating systems are available; however, these are seldom comparable between plant species or evaluators. If these are used, then they should be defined. Percentage injury is probably the most appropriate system to be used as it can be directly measured.

Another method is the use of percentage scales or keys which can be compared with injured foliage samples. Percentage injury can be incorporated into both the numerical and relative severity systems. A value in either of these systems will be applied to a range of percentage injury, as shown in the Table 2.

Table 2: Leaf Injury Rating

Injury Category	Percent Injury (Area Basis)
Healthy	0
Trace	0-1
Light	2-10
Moderate	11-35
Severe	>35

Symptoms of injury exhibited by foliage can be placed in several main groups depending upon the pollutant involved. These include necrosis, chlorosis, flecking and stippling, glazing or bronzing, anthocyanosis, and particulate deposits. The locations of these injuries on the leaf may be diagnostic, therefore, the positions of injury should be recorded as being primarily terminal, marginal or intercostal. The percentage of the total leaf area, where the injury symptoms are present, is recorded. Evaluation of chlorosis and anthocyanosis is somewhat subjective and must be compared with the normal color expected for the same type and age of leaf. Particulate evaluation might be achieved by two methods. The first method is to count the number of particles in a given area of the leaf if the number and size of particles is suitable for this approach. In the case of a heavy coating of particulate on foliage, the amount of particulate could be determined by washing a constant number of leaves in a fixed volume of washing solution. If the leaf area is known, and the particulate in the wash solution is analyzed for specific tracer elements, then the particulate loading to the foliage can be computed.

The assessment of injury severity also can be made on the basis of the overall appearance of the plant. This type of rating is most useful in determining long term effects of foliar injury on perennial species. To assist the evaluator in this type of assessment, two classification systems have been developed for use in the field and are described below.

Table 3: Crown Condition Classification System for Coniferous and Deciduous Trees

Rating	Description
1	Near Perfect
2	High quality forest tree with self-pruning of shaded branches
3	Tree in good condition, may have 1 or 2 dead branches
4	Tree in fair condition with 3 or more dead branches
5	Up to one-half of crown dead
6	One-half to 75% of crown dead
7	75-90% of crown dead
8	Over 90% of crown dead, some branches retaining foliage
9	Branches with few live needles/leaves still attached
10	Tree dead

Table 4: Foliage Retention Classification System for Coniferous Trees

Rating	Description
1	Foliage retained over 2 years
2	Over 2/3 of 2 year old foliage retained
3	Less than 2/3 of 2 year old foliage retained
4	Less than 1/3 of 2 year old foliage retained
5	Over 2/3 of 1 year old foliage retained
6	Less than 2/3 of 1 year old foliage retained
7	Less than 1/3 of 1 year old foliage retained
8	Only current year's foliage retained
9	Less than 2/3 of current year's foliage retained
10	Only 1/3 or less of current year's foliage retained

2.2 Yield and Growth Assessment

2.2.1 Seed Crops

The best overall measure of yield of seed crops is to measure the quality of seed harvested by normal farm methods (provided that they are done carefully) and divide this quantity by the total crop area. This resulting value is the yield and is usually expressed as bu/A, tonnes/ha, etc. This large-area approach may not be applicable in certain circumstances of localized sources of contaminants which may affect only a portion of a crop. In this case, small sample plots can be established over the field in such a manner that both affected and unaffected areas are sampled for comparison purposes. Such sample plots should be selected to show the distribution of affected crop plants with care being taken to minimize the effects of other edaphic variables on crop yield.

As a minimum, it is suggested that not less than six areas are sampled: control area (2), affected area (2), intermediate area (2). All plots locations must be accurately mapped and the sample plots should cover not less than 1m² in area. The plots should be harvested at maturity and the grain, straw and chaff weighed. A weight measure of a constant number of seeds (100) will also provide information which can be used to calculate seed

size and/or the total number of seeds harvested. When these results are reported it should be noted that the yields will be higher than could be expected by the grower due to the greater efficiency of the harvesting procedure compared to normal farm practices.

2.2.2 Forage Crops

The best overall measure of yield of forage is to determine the quantity harvested by normal farm methods taking the total crop area into consideration. This can be done by weighing random bales of hay and calculating the total crop weight from the number of bales harvested. Other techniques may be used for forage prepared in other ways. If localized sources of contaminants are involved or if the forage is utilized in the context of a pasture, then biomass sampling techniques can be adapted. Sample locations should be selected using the same technique as outlined in Chapter 4, Section B (2). Such sample locations must be accurately mapped and each should cover an area of not less than 1m x 1m.

Plots are harvested at normal harvest time. The fresh and dry weight of samples are determined and samples may be processed for various additional analysis. The data are compiled to determine the net impact of the localized pollutant on yield.

2.2.3 Vegetable Crops

The variety of difference vegetable and speciality crops requires that each type of crop be measured according to its own yield parameters. These can be various combinations of the following parameters.

Yield Parameters	Unit Basis
Number of individual fruits or vegetables	Per Plant
Total weight (fresh or dry basis)	Per length of planting row
Volume (litres, quarts)	Per unit crop area

2.2.4 Growth Parameters

a) Plant Height

Plant height is measured from ground level to tip of the uppermost meristem.

b) Plant Weight

Fresh weight measurements should be taken immediately following field collection to prevent any changes due to desiccation.

Dry weight measurements should be taken after plant tissues have been oven dried at 105°C for a period of 24-48 hours. In some cases, air dry rather than oven dry weights may be measured to generate yield data on a 12-14% dry matter basis for comparison with published, adjusted crop yield values. Sample weights can be taken from either whole plants or portions of plants (i.e. leaf, fruit, roots, etc.).

c) Leaf Size

Leaf size is measured from the junction of the petiole and leaf lamina along with the main vein to the tip of the leaf. Several methods can be employed in measuring leaf area.

- LI-COR leaf area meter
- dot grid
- imprints
- mechanical scanner
- traversing

d) Shoot Length

Shoot length measurement should be taken from the previous season's growth or the start of the current season's growth (terminal bud scar) to the tip of the meristem.

e) Stem Diameter (D.B.H.)

The measurement of Diameter at Breast Height (1.5 m) of the trees should be made in the same way as when cruising the forest or sample plot. The diameters are usually measured to the nearest millimeter, using a diameter tape.

It is convenient to paint bands around trees to be measured at breast height levels such that subsequent measurements will always be made at the same position. When measuring forked trees, the stems that fork below D.B.H. are considered to be two separate trees. Figure 2 illustrates suggested methods for maintaining consistency in obtaining diameter measurements.

f) Stem Analysis (Growth Layer Analysis)

Stem analysis is a technique which enables an investigator to examine how the growth of an individual tree has changed with time. The required measurements can be taken from a standing tree with an increment borer and diameter tape (non-destructive); or, by felling a tree, cutting it into sections and removing disks from the sections for detailed measurements in a field camp or laboratory (destructive). If destructive stem analysis is conducted it is normal to use a single tree with the results intended to be representative of a local population. In that case care should be taken to select a tree which is close as possible to the average height and age of the forest stand being studied. If recent timber cruise data are not available then average stand height (of the study species) can be quickly determined in the field using a clinometer or other height measuring instrument. The stem analysis procedure is quite straight forward, as follows:

1. Select a tree of average stand characteristics and fell at a 30 cm stump height using a cut at right angles to the hole.
2. De-limb and remove all debris from the work site. This takes extra time but minimizes the chance of accidents while using power equipment.
3. Determine and record species, diameter breast height (DBH) to the nearest 10th cm and total height to the nearest 10th m.
4. Cut the stump at the root collar, or 0 height, and determine the number of years to reach stump height ($= \# \text{ rings at } 0 \text{ ht.} - \# \text{ rings at } 30 \text{ cm stump cut}$) and the total age of the tree.
5. Decide on the length of tree sections to be cut; 1 cm intervals are most frequently used, although longer and irregular lengths can also be applied, particularly when sectioning hardwoods or very tall trees. Mark the desired intervals on the felled tree starting at the 30 cm cut and progressing right to the tree top. Cut the sections at right angles to the bole at each marked segment and label immediately. Remove a disk from the bottom of each section including the 30 cm stump and the less than 1 m top, label immediately, and measure and record the length of the tree tip. The tree disks can now be removed from the site and measurements concluded at a field camp or laboratory.
6. Determine the mean (inside bark) diameter of each disk. An accepted method of determining mean diameter is the average of two diameter measurements taken at right angles to each other.

7. Determine the mean (inside bark) radius of each disk. This is simply $1/2$ of the mean diameter. Mark the mean radius on the cleanest face of each disk. It is along this mean radius line that all ring counts and growth measurement are made.
8. It is often necessary to prepare the disk so that the annual rings are easier to distinguish. A belt sander using a coarse followed by a med/fine sanding belt is most appropriate for removing the saw ridges and smoothing the wood face. This also exposes the entire cross section of the disk to examination. However, if this is not available then a V shaped notch cut with a razor knife along the mean radius line produces a clean path of observation. Depending on the tree species the growth rings may still not be clearly visible, as is essential for accurate measurement. Rubbing glycerine or petroleum jelly along the observation radius usually enhances the rings sufficiently to allow for examination with the naked eye, hand lens, or low power microscope.
9. Along the mean radius of each disk count and record the number of annual rings from the cambium in toward the pith. Mark every 5th year (from the cambium). Although 5 year growth intervals are most frequently used a 10 year or longer span may be more practical if the tree is particularly old.
10. On each disk measure and record (in mm) the distance along the mean radius from the pith to each 5 year interval. The fractional portion, that less than the established interval closest the path, will always be recorded first.

With data obtained from stem analysis it is possible to construct ht/age, dia/age and if required ht/dia curves for specific trees. It is also possible to determine the wood volume of any section of the tree, the total volume and more importantly the volume of wood produced at any given period of time in the tree's history. Although the procedures for the various volume calculations are quite straight forward the format for the data set-up can be quite lengthy and need not to be discussed in detail here. For complete information on growth and volume measurements refer to Husch, Miller and Beers "Forest Mensuration" 1972 Ronald Press Co.

The section volumes which are of the same age are added up to obtain the volume of the total tree and converted to cubic meters to the closet .0001 m³.

The length of the sections are all 1 m or 100 cm except that the first section which is .3 m or 30 cm and that of the youngest age class. This youngest age class section is assumed to be conical in shape, with a basal area equal to that

of a circle having a radius the distance from the outer ring to the pith.

Table 5: A Comparison of Two Stem Analysis Techniques

Tree Ring Incremental Measurement System (TRIM)	Tree Ring Increment Core System (TRICS)
-annual tree volume (dm ³)	-annual tree increment
-measures tree rings on disks to 0.01 mm	-measures tree rings on increment cores to 0.01 mm
-sampling is destructive and time consuming	-sampling is non-destructive and relatively easy
-can measure 1 tree per day	-can measure 20+ trees per day
-results are tree specific; choose an average tree	-results are tree specific, but averaging function of software allows aggregation of individual data files to create mean data
-complicated to use and interpret	-relatively easy to use
-data is precise	-measurement is precise, but relationship is inferred
-excellent documentation	-documentation is marginal
-excellent graphic support	-adequate graphics, but files are compatible for compositional flexibility (printographer)
-no data statistical support	-descriptive statistics (means, SD, VAR, max., min.) plus INDEX for tree age and RATIO for climate filtration plus VISI compatibility
-measuring table is inconvertible	-measuring table has hair trigger, use caution to avoid data errors

Hints for Collecting (Good) Increment Cores

1. follow the instructions supplied with new instruments
2. use a sharp, clean (clean with turpentine), well-oiled corer
3. core round trees at a standard height (DBH 1.5 m)
4. avoid trees on slopes (avoids compression, tension wood)
5. insert corer at very slight upward angle
6. visualize tree centre and aim for it
7. apply strong, even pressure until screw bit has caught wood (minimizes crushing of 1st few rings)
8. remove corer immediately
9. insert extractor all the way, turn corer half way in both directions
10. collect 2 cores per tree to permit cross-checks
11. store cores in large diameter plastic straws
12. freeze cores if not measured soon

Annual tree ring widths are measured generally by two different methods, one non-destructive, the other destructive. In the first, 5 mm diameter cores are cut with a commercially available increment borer at approximately 1.5 meters above the ground. In the second the tree is cut down with a chain-saw and stem (trunk) disks harvested at predetermined intervals along the trunk.

A comparison of two automated tree ring measurement systems, representing the above methods, as well as additional hints for collecting good increment cores, is presented below.

2.2.5 Quality Parameters

In all cases where quality of crop produce or wood products are to be evaluated, the standards for grading to be applied will be those developed for individual crops by the Ontario Ministry of Agriculture and Food the Canada Department of Agriculture, or the Ontario Ministry of Natural Resources.

2.2.6 Reproductive Potential

The stress of air contaminants on vegetation may be manifested in reduced yield or reproductive parts of the plants (fruits, seeds) or in reduced viability of the seed. The consequence of this latter effect would be a lowering of the value of commercial crops in quality and/or quantity which could lead to shifts in species composition in natural or uncultivated areas.

In the absence of any background information, many plant seeds may be tested by germinating them in petri dishes. It is suggested that conditions for initial tests include placing several lots of 25 seeds in petri dishes lined with filter paper. Approximately 2 ml distilled water are added to the dishes which are incubated in the dark at 25°C. The dishes are examined periodically to evaluate germination and to ensure that the filter paper have not dried out. Additional water may be added periodically as required.

Germination is scored if the length of the emerging radicle is equal to the diameter of the seed. Additional tests might include measurement of the length of primary roots after different periods of time.

If the above test method is found to be unsatisfactory, the various conditions may be modified to suit the particular conditions involved. Consideration should be given to scarification or stratification of seeds as required.

3 FIELD INVESTIGATION PROCEDURES

3.1 Vegetation Assessment Surveys

3.1.1 Survey Type or Emphasis

The form of the assessment survey will depend on the type of containment being emitted by the source. Essentially, most surveys will have two major components: 1) inspection of vegetation for injury and 2) sampling of vegetation (usually foliage) for analysis for contamination. Table 5, below summarizes the importance that should be placed on each of the two components for several different contaminants.

Table 6: Assessment Survey Emphasis or Various Air and Soil Pollutants

Pollutant	Assessment Emphasis
Ammonia	injury inspection only
Arsenic	injury inspection + vegetation sampling
Boron	injury inspection + vegetation and soil sampling (plant available)
Chlorine	heavy emphasis on injury inspection; less emphasis on vegetation sampling
Chloride	injury inspection + vegetation and/or soil sampling
Fluoride	injury inspection + vegetation sampling
Heavy metals	heavy emphasis on vegetation and/or soil sampling; less emphasis on injury inspection - some injury could be expected under very heavy contamination situations with certain metals
Hydrogen chloride	acute: heavy emphasis on injury inspection; less emphasis on vegetation sampling
	chronic: per chloride
Hydrogen fluoride	acute: heavy emphasis on injury inspection less emphasis on vegetation sampling
	chronic: per fluoride
Mercury	heavy emphasis on vegetation and soil sampling less emphasis on injury inspection
Ozone	injury inspection with histology backup
Petroleum products	injury inspection + soil sampling
Sodium chloride	per chloride
Sulphur dioxide	heavy emphasis on injury inspection moderate emphasis on vegetation sampling where chronic sources concerned.

3.1.2 Survey Configuration or Layout

Three general types of assessment surveys layouts are routinely used; the radii system, the quadrant system and the grid system. Each of these layouts can be modified in turn to

suit the particular needs of the investigator. Figure 3 outlines each general type and one of the possible modifications of each. The advantages and disadvantages of each general type of survey are listed presented in Table 7.

Sampling sites should not be established in the vicinity of dusty gravel roads, paved highways, or other possible emission sources.

Table 7: Comparison of Different Sample Collection Configurations

Sample Collection System	Advantages	Disadvantages
Radii	Can be set up quickly and suits areas where roads run at right angles; good for untracked forest areas or where distances must be covered	Large areas between the arms can be missed as distance from the source increases
Quadrant	Combines the quick nature of the radius system with the coverage provided by the grid system	Not as suitable where trends along a particular line from the source are to be determined
Grid	Can provide a very comprehensive picture suitable for symapping; the risk of missing high contamination areas are minimized	Costly since stations usually number in excess of 25; often difficult to carry out due to lack of suitable sampling points

3.1.3 Species Selection

Wherever possible, the same plant species should be sampled at each site in the survey in order that data comparisons can be made between sampling sites. In southern Ontario it has been commonplace to use silver, Manitoba or Norway maples, with the result that a large data base has been established. If it is not possible to collect a single common species, two species may be selected such that at any given site, either one or the other, but preferably both, would be collected. Where ever this degree of uniformity is difficult or impossible, complementary support studies such as moss bags or indicator plots should be considered.

There are instances where apparent "accumulator" species should be avoided. These include:

zinc and cadmium:	Salix sp., Populus sp. and white birch
sulphur:	tomato and numerous grasses
boron:	Manitoba maple
chloride:	hickory, American elm, spinach

3.1.4 Survey Timing

Assessment surveys for vegetation contamination are commonly carried out in August and September. Earlier surveys may miss significant contamination buildup; later surveys may be compromised by an early leaf fall.

The amount of rainfall received prior to the tree foliage collection may affect contaminant concentrations. For example, studies have shown that rainfall may be the single most important factor in explaining year-to-year variation. Apparent decreases or increases in emissions from a source, based on foliar sampling, may be invalid if rainfall variation has not been examined. The effect of rainfall may be large where the contamination is principally emitted in particulate form, but may be insignificant for emissions of gaseous contaminants. The potential significance of rainfall can often be judged by the difference between results for "not-washed" and "washed" samples. Foliar surface characteristics (cuticle roughness, pubescence etc.) may be an important variable. Episodic variation in rainfall pH may also be significant in some cases.

Since even year to year changes in soil concentrations are usually very small for most contaminants and sources, soil surveys can be carried out at any time when the soil is not frozen. In the case of gaseous or phytotoxic contamination, surveys should be designed to ensure visual inspection and/or sample collection during the early, mid- and late season periods.

3.1.5 Control Site Selection

Controls for assessment surveys should be chosen from locations that best replicate the environmental conditions in the vicinity of the source, but are out of the zone of influence of the source emissions. This may be difficult around new sources where the extent of contamination is not known; however, adjustments of control zones in follow-up surveys is acceptable. Controls should be collected for all plant species and soils collected in the survey zone and should be subject to the same sampling method guidelines as samples from the main body of the survey. Controls should be selected from areas with similar vehicular, residential and industrial activity as the source area.

3.2 Auxiliary Support Techniques

In certain instances, auxiliary support studies are carried out to augment the main assessment survey or complaint investigation. These complementary studies are usually initiated in cases where there is an inherent deficiency in the basic survey layout such as the

lack of suitably sensitive plant species in the survey area or the lack of plant species suitable for chemical analysis sampling. Various types of auxiliary support are discussed separately in the following sections:

3.2.1 Indicator Plots

Living plants have been used for decades by numerous researchers and control agency personnel as indicators of the adverse effects of air pollution. Although "in-situ" vegetation can be used, it is possible to set out specimens of specific clones which have known histories of high sensitivity to be one or more air pollutants.

The effect of this exercise is to extend the range of sensitivity of observable plant material at one or more chosen locations in a study area.

An outline of the classification of air pollution indicators is shown in Fig. 4. At the extreme left are those groups of plants referred to as indicators. These groups are simply native species or species introduced as crops or ornamentals which are already present in the area before commencement of the study. The principal advantage of using such plant groups is that the data extracted from the study are wholly relevant to local growers or other concerned individuals. It may not, however, be possible to demonstrate a good correlation between the air quality data and plant response. Environmental conditions such as temperature, humidity and rainfall may alter greatly the susceptibility of these groups. Since these groups probably do not represent cloned material, plant to plant variability can be high. At the extreme right of Figure 3 are groups of plants referred to as monitors. Their advantage is a normally good correlation between pollution concentration and injury development; their principal disadvantage is lower relevance with respect to locally grown crops or ornamentals. There are several references available that describe various indicator plot techniques including the following:

1. Air Pollution Control Assoc. (1978). Handbook of methodology for the assessment of air pollution effects on vegetation. APCA Upper Mid-west Section.
2. Manning W.J. & Feder W.A. (1980). Biomonitoring air pollutants with plants. Kenneth Mellanby ed., Applied Science, London.

A technique developed by the Phytotoxicology Section for monitoring ethylene in ambient air is described in a separate publication available from the Phytotoxicology Section.

3.2.2 Moss Bag Ion Receptors

Networks of standardized Sphagnum moss bags have been used for several years to monitor atmospheric emissions from numerous sources. Successful results have been achieved with the following elements; Pb, Cd, Ni, Zn, Co, Cu, Sb, Hg, As, Na, Ca, Cl, B, F, F, Al, Cr, and S. It has been determined that B, Cl and Na may be leached from moss bags by rainfall; therefore, a shorter exposure period or a system of wet weather protection is suggested for these elements.

The moss is purchased from a local supplier who has promised consistency of origin, moss quality and a reliable inventory. Using plastic or latex gloves, the moss is hand cleaned to remove sticks, stems, dead leaves and other assorted field debris associated with commercially packaged moss. The fibres of moss are placed in plastic sample bags which are then filled with distilled water and left to soak overnight. The following day, the moss is rinsed three more times with distilled water and spread on plastic drying racks for a minimum of 48 hours.

Several samples should be collected and analyzed from each batch to determine the contaminant levels inherent in the moss. Experience has shown these pre-exposed batch control samples to be very consistent for most elements; however, this does not reduce the need or importance of field exposed control samples for all moss bag surveys.

Polypropylene screening with a mesh size of 1.5 x 2.0 mm is cut, folded and machine sewn to the dimensions illustrated in the accompanying Figures 5 and 6. Sleeves are sewn on the short side of the rectangular shaped screen bag to accommodate the plastic field holder. The moss bag is completed with the insertion of 3.0 ± 0.1 g of air dried moss into the screen pouch, spraying with distilled water to work the moss into the corners and sewing the bag closed. The pouch measures approximately 15.5 x 6.5 cm and provides approximately 100 cm² of moss surface area. The completed moss bag is left to air dry before being placed in plastic bags for refrigerated storage. The plastic bags should be labelled with the appropriate moss wash number so that future comparison can be made with the analytical control data.

The field exposed moss bags should be utilized in conjunction with the plastic moss bag holder and support tube (Figure 7). The side mount style is generally preferred to that of the front mount, which has limited application. The tube can be permanently attached in areas where surveys are conducted over several seasons. Moss bags should be attached to the pole/tree/structure about 3 m from the ground (min. 2.5 m, max. 3.5 m), but in areas where there has been repeated vandalism, it may be advisable to place the bags somewhat higher. Past experiments have shown that contaminant levels in moss can vary at the same site when the bags are oriented in different compass direction relative to the source; therefore, it is recommended that the flat surface of the moss bag be pointed directly at the point of emissions.

The usual exchange time is one month, considered to be 28 to 31 days duration. It is important to have at least one good control site so that local background levels can be recognized. Exposed moss bags are assigned field numbers and placed in individual paper enclosure bags which are stapled closed. On arrival in the Processing Laboratory, the paper bags require no processing and can be placed directly in the drying ovens. After drying, the polypropylene screen is cut away prior to homogenizing the moss in a Wiley mill. One exception to the oven drying process is moss bags for Hg analysis. These must be air-dried.

3.2.3 Bioassay Growth Studies

Bioassay growth studies can be used in a support of complementary role for all types of field investigations. Basically, these are special studies which are designed to provide information pertaining to adverse vegetation effects which otherwise would not be generated through the use of normal field investigation procedures. Although the designs and methods employed in these studies are virtually infinite in scope and defy the

preparation of rigid methodology procedures, they are, nevertheless, several key rationales applicable to all types of terrestrial vegetation on which the majority of these studies have been based.

- a) to determine the relevance of soil contamination
- b) to differentiate between air and soil-borne contamination
- c) to determine or estimate the longevity of soil contamination
- d) to differentiate between multiple air-borne contaminants or mission sources
- e) to establish guidelines for the removal and replacement of contaminated soils
- f) to identify and quantify the adverse effects of contaminated water supply

In any study of this type there are always several basic design considerations which must be addressed prior to formulating the experimental plan.

Some of the key considerations have been listed below:

- a) Should the study be conducted "in-situ" as opposed to the clean air greenhouse or garden location?
- b) What type of growth container will best suit the experimental objectives? i.e. pots, flats, "in-situ" planting, petri dishes
- c) What type of plants should be used in the study? i.e. native or natural species vs. common greenhouse or indicator species
- d) What type of soil medium should be used?
- e) What type of irrigation water supply should be used? i.e. local water supply vs. greenhouse or distilled water source
- f) What type of plating method will be most suitable? i.e. direct seeding vs. transplanting
- g) Should pest control practices be employed? i.e. spraying for insect and disease control vs. hand rouging
- h) What type of fertilizer regime (if any) should be maintained?
- i) Should the study focus on germination effects, growth/yield impediment, foliar injury potential or reproductive effects?
- j) How long should the study run? i.e. short term vs. long term effects
- k) What type of environmental conditions should be monitored or maintained?
- l) What degree of accuracy or confidence is required in the interpretation of the data? i.e. how many replications required?
- m) What types of data will best convey or describe the results of the bioassay? i.e. measurements, photographs, chemical, pathological or histological information

Regardless of the type of bioassay methodology employed, the information which is generated will not be scientifically credible unless all information pertaining to the design rationale, experimental techniques, climatic and edaphic parameters and data generation and statistical analysis are considered in detail so as to permit validation of the results at a later date. If the bioassay is to be conducted at the Controlled Environment Laboratory, discussion of the project with laboratory staff prior to project start-up is essential.

3.2.4 Leaf Litter Bags

Environmental stresses may not be as readily apparent as wide-spread destruction of the dominant types of vegetation. It is possible that continued stresses (i.e. fallout of metals) would have a negative effect on the biological components of the environment. This negative effect could be rather subtle and take some time to become obvious. One possible method of monitoring the subtle effects is to investigate the processes elemental cycling in the environment. This cycling process might involve contaminants (in the foliage) which, upon reaching the soil, could affect biological agents involved in these natural cycling processes. Monitoring changes in the populations of these agents or their collective rate of activity (rate of leaf litter decomposition) may be accomplished by placing fixed amounts of leaf litter in the areas to be investigated and periodically following the fate of the leaf litter. By comparing the rates of decomposition in the area being investigated with those of a control area, it may be possible to determine if (and how) the environment is being affected.

- a) Samples of test foliage or leaf litter are brought to the laboratory and stored temporarily at 4°C
- b) Samples are dried if required at 105°C for 48 hours. Since this may be detrimental to certain types of organisms in the samples, it may be preferable to air dry samples. Similarly, fresh samples may also be used. However, when either fresh samples or air dried samples are used, a sub-sample must be oven dried to determine the moisture content, for calculating the dry weight of material placed in the bags.
- c) Litter bags are prepared from fibreglass screening with 1 mm square opening. This size of mesh retains smaller particles of decomposing foliage; however, it also excluded some of the larger soil arthropods. Mesh sizes must be chosen as a compromise between these two factors.
- d) The screening material is cut into 23 x 30 cm rectangles. These are folded and the shorter side are sewn together with invisible thread 3 cm from the edge to form a pouch
- e) Ten grams of dried leaf material are placed in each envelope which is then sewn closed
- f) Prepared litter bags should be numbered and weighed prior to placement in the field if the contents are to be weighed and extracted for arthropods, etc. after collection

- g) Prepared litter bags are placed in the field in a predetermined experimental plan. Bags should be placed on the ground at a level comparable to the leaf litter represented by the material within the bag.
- h) Litter bags are exposed for various periods according to the experimental plan
- i) Litter bags are collected, placed individually in plastic bags and transported in coolers to the laboratory
- j) Bags are weighed, extracted for arthropods, dried, processed for chemical analysis, etc. according to experimental plan.

4 SAMPLE COLLECTION PROCEDURES

4.1 Vegetation

4.1.1 Inorganic Chemical Analysis

4.1.1.1 Tree and Shrub Foliage

Trees or shrubs should be sampled on the side facing (fully exposed to) the source(s) by removing as many small shoots as possible in order to properly represent the tree or shrub being sampled. That is, the shoots selected should be well distributed across the exposed side of the plant. A minimum of 10 such shoots, each representing the entire current year's growth, should be cut from each tree or shrub sampled. Evergreen foliage should be collected in a similar manner except that different years' growth should be bagged, identified and processed separately. Foliage should not be permitted to fall on barren soil or gravel surfaces during sampling, and should not be set down on these or other potentially contaminated surfaces prior to bagging. More than one specimen of the same species can be sampled at each site provided each is adequately exposed to the source. Foliage should be removed from the twigs with reasonable care in order to minimize tearing. As sampling errors have been established from past years' data for most of the major study areas and can be used as inference for future sampling, all foliage of the same species may be bulked to form a "composite" sample for each sample from each sampling site, and placed in a single bag with its appropriate identification number. Place all samples in unused plastic bags, enclose field number, expel air and tie or knot. All bags should be punctured to retard spoilage of foliage.

At the discretion of the investigator-in-charge certain modifications or additions to the above may be made:

- i) In new survey areas, in areas where past surveys have revealed a high degree of variability or in areas where the data may be challenged (court cases, control orders) it is recommended that replicated (2 or more) sampling be conducted at each site. This will permit attachment of statistical confidence limits to the sampling results;

- ii) Where a question may later arise with respect to source identity (multiple sources), an investigator- in-charge may choose to separately sample those sides of trees or shrubs considered protected from the source. By repeating this "side facing/side away" procedure at several locations around the suspected sources, a firmer case may be developed.

4.1.1.2 Forage

The collection of forage is usually restricted to those areas where contamination of livestock feed may have occurred. At each sampling site, forage should be sampled in as random a manner as the site will permit. In an open field where such randomization is easiest, samples may be collected using predetermined co-ordinates from a random numbers table or an "M" "X" "W" or "Z" pattern which can be walked in the field. A unit of the sample is defined as having been collected each time a sampler cuts a portion of forage.

As a guide to the number of units of the sample that should be collected, reference is made to the coefficient of variation (CV = standard deviation/mean) determined from past years' sampling for each sampling site. The table below shows the number of units of the sample that should be collected in order to achieve the stated accuracy for the known coefficient of variation. In cases where the CV is not known, a minimum of 10 units should be collected (15 recommended for single sampling).

Table 8: Number of Sample Units Required for Indicated Coefficient of Variation

Desired Accuracy of Estimate	Coefficient of Variance								
	.10	.12	.14	.16	.18	.20	.30	.40	.50
± 5%	16	23	31	41	52	64	144	256	400
±10%	4	6	8	10	13	16	36	64	100
±15%	2	3	4	5	6	7	16	28	44
±20%	1	2	2	3	3	4	9	16	25

The sampling procedure with forage can be modified as in 4.1.1.1 above, where a high degree of intra-site variability is suspected. Forage is usually collected in a manner which will best approximate a grazing animal; that is, the top 15 cm of new growth is cut. Old, dry grass stems from the previous year's growth should be avoided, as should unpalatable weeds and sedges. Record approximate species composition, whether grazed, or combination. Place all samples in unused plastic bags, enclose an identifying label, expel air and tie or knot the bag.

4.1.1.3 Garden Produce

Garden produce is normally sampled only where there is concern over consumption of contaminated fruits or vegetables. In these instances, samples should be collected with a view to obtaining results on an "as consumed" basis (see Appendix G-2). Consequently samples should be in a harvestable (i.e. natural) condition. For root and leafy vegetables a sufficient quantity of either the entire plant or the consumable portion should be collected and placed into the standard plastic sampling bag, which is then labelled, tied and perforated to retard spoilage. During warm weather, it is preferable to place the sample bags in an insulated cooler for transport to the sample preparation laboratory.

4.1.2 Organic Chemical Analysis

The basic methodology for collection of vegetation samples for organic chemical analysis (including pesticides) is the same as that for inorganic analysis described in the preceding section. However, samples must be collected in solvent rinsed, amber-coloured glass jars. The reader is referred to Section B (Soil) Part 5 (Organic Chemical Analysis) below, for more detailed procedures for organics sampling.

4.1.3 Radioactivity

(to be added)

4.2 Soil

4.2.1 Inorganic Chemical Analysis

4.2.1.1 Total Levels

Contamination is assessed by sampling soils at the 0-5 cm depth or by multi-depth sampling (0-5, 5-10, 10-15 cm) using a standard soil core (Oakfield) borer or stainless steel spoon or shovel if the soil is too stoney to permit the use of the borer. Like forage samples, soil sampling is carried out in as random a manner as the site will permit using a coordinate system or the "M" "X" "W" or "Z" pattern described for forage. Like forage sampling, the final composite sample from each site is comprised of numerous units, a unit being defined as a single core. This number, which must not be less than 10 cores (15 recommended for single recommendable for single sampling), should be maintained regardless of the site area. The recommended standard area for a single sample in an open field is a 2 m radius circle. Where multi-depth sampling is carried out, samples from each depth are bulked separately. Neither surface leaf litter nor debris should be knowingly included in the sample. The soil core borer should be cleaned between sites.

Other sampling may be employed at the investigator's discretion. If the Coefficient of Variance is known, the number of units can be based on desired accuracy of estimate. Record soil type (sand, loamy-sand, sandy-loam, loam, silt-loam, silty clay-loam, clay-loam, sandy-clay, silty-clay, clay, coarse aggregate, organic, greenhouse). If necessary the soil type can be determined from particle size measurements in the laboratory. For triplicate sampling, each replicate should contain a minimum of 10 units collected in 2 or more separate passes over the area. All samples should be placed in unused plastic bags with appropriate identification.

4.2.1.2 Plant available or Extractable Levels

The sampling procedure for this type of analysis should be similar to that described for total contamination. The only difference is that a more meaningful value with respect to plant uptake can be obtained from samples collected from the plant root feeding zone: 0-15 cm for most crops and ornamentals. In view of the intimate relationship between soil reaction (pH) and contaminant "availability", it is recommended that pH be recorded for all samples collected for extractable content.

4.2.2 Fertility

Fertility samples are collected in the same manner as samples for total contamination except with respect to depth. Soils for fertility are collected in the plant root feeding zone: 0-15 cm for most crops and ornamentals.

4.2.3 Lead in Residential Soils

The following protocol has been developed for soil lead sampling for the purposes of determining blood lead/soil lead relationships and/or eligibility for soil replacements.

4.2.3.1 General Sampling Guidelines

- Standard sampling depth is top 5 cm, which should be maintained unless prevented by hard-packed soil conditions or other obstacles (Gardens should be sampled to 15 cm depth).
- Samples normally are collected with a standard Oakfield sampler by walking the site in a random manner or along a predetermined pattern (e.g. W, X, or Z).
- Duplicate samples should be collected at each site.
- A minimum of ten, 0-5 cm cores constitute a single sample.
- Sample cores should not be taken closer than 0.5 m from roadways, buildings or fences. (These areas may be sampled separately, if desired, to determine local effects of auto exhaust or peeling paint).
- Where hard-packed, coarse or loose, sandy soil is encountered, a trowel may be used to collect the samples, to a minimum depth of 2 cm (depth to be specified).
- Samples should be collected directly into clean, labelled plastic bags for transport to processing facilities.

4.2.3.2 Site Selection

- Sampling sites on residential properties should consist of discreet or semi-discreet, easily identifiable areas such as: front yard lawn, backyard lawn, driveway, vegetable garden or child's play area.
- A minimum of two sites per residential property should be sampled. (Sample all sites if eligibility for soil replacement is being determined).
- Sampling in school yards and parks should focus on sites frequented by children, such as playing fields, near swings, etc.
- A minimum of three sites per park or school yard should be sampled.

4.2.4 Conductivity Determinations

The basic procedure for collection of soil samples for determination of electrical conductivity (total salts) is the same as previously described for samples for inorganic chemical analysis. Measurements can also be conducted on a sub-sample taken from samples collected for other purposes (e.g. fertility). Because determinations of conductivity are relatively simple and inexpensive, it is recommended that samples for conductivity measurements be collected in all cases of both suspected salt injury and where there is any doubt as to the nature of the problem being investigated (i.e. injury suspected of being due to other causes). A discussion of the interpretation of soil conductivity results is contained in Appendix G-3.

4.2.5 Organic Chemical Analysis

The basic methodology for soil sampling for trace organics (including pesticides) is the same as that for inorganics described in the preceding section. However, the following additional procedures should be adhered to.

4.2.5.1 Avoidance of Cross-contamination

Soil sampling for trace organic contaminants requires special techniques in order to avoid contamination both from other samples and from sampling equipment and containers. Equipment must be rinsed with organic solvents to remove all traces of previous organic residue. Also, it is very important that neither the sample nor the sampling equipment (soil corers, insides of sample containers, solvents) come into contact with plastic (vinyl or polyethylene) materials during the sampling program, due to the presence of phthalate in these materials. This means that plastic gloves should not be worn. Where potentially dangerous levels of contaminants are suspected, protective gloves made of solvent-resistant material (e.g., latex) should be worn. However, neither gloves nor bare hands are to contact the sample directly. Rather than transferring the soil cores from the corer to the sample container with bare or gloved fingers, a stainless steel spatula or knife should be used.

Solvents used to clean sampling equipment must not be placed in plastic bottles. Use teflon or glass only. Storage of distilled water and alconox solution in plastic containers should not pose a problem because subsequent rinsing with the organic solvents (acetone, hexane) will remove any trace amounts of phthalate present on the sampling equipment.

4.2.5.2 Equipment Cleaning Procedure

All sampling equipment which contacts soil directly (i.e. corers, knives) must be scrupulously cleaned between sites. The recommended cleaning procedure is as follows:

1. Remove adhering soil particles by scrubbing with dilutealconox (soap) solution.
2. Rinse thoroughly with distilled water.
3. Rinse with acetone (from Teflon squeeze bottle).
4. Rinse with hexane (from Teflon squeeze bottle). Note: Avoid direct skin contact with solvents.
5. Allow equipment to air-dry for five minutes before sampling.

4.2.5.3 Sample Containers

The standard sample container for trace organic analyses is the solvent-rinsed, wide-mouthed 250 ml amber-coloured glass jar with foil-lined lid. This should be filled at least three-quarters full with sample. This jar is suitable for all classes of organic compounds (incl. PAH's, PCB's pesticides) analyzed by our Resources Road laboratory and the OMAF pesticides laboratory in Guelph.

4.2.5.4 Sample Preservation

The samples, with lids screwed on tightly, must be kept cool (refrigerated) until delivery to the analytical lab. If highly volatile compounds are of concern, it may be advisable to freeze the samples, particularly if a lengthy delay is anticipated prior to analysis. This should be discussed with laboratory staff.

4.2.6 Site Remediation or Decommissioning

4.2.6.1 Determination of Degree of Contamination

Sampling requirements for site remediation or decommissioning (i.e. determining necessity of clean-up) will vary on a case-by-case basis. Concerns may extend beyond that of simple phytotoxicity to those of human health or groundwater contamination. The normal procedure is for the proponent to retain a consultant to carry out investigative sampling. This should be undertaken in consultation with M.O.E. regional staff. The Phytotoxicology Section will provide comment/advice upon request.

Complete instructions for site decommissioning are contained in the Ministry of the Environment publication "Guidelines for the decommissioning and cleanup of sites in Ontario" (February, 1989 or later revision)

4.2.6.2 Post-clean-up Verification Sampling

Phytotoxicology Section or Regional Technical Support staff may be requested to carry out post-clean-up verification testing. As a minimum, in areas not to be permanently covered over, contaminant concentrations in at least the upper 30 cm of soil (as measured in any 5 cm increment) should meet the M.O.E. clean-up guidelines. Site-specific factors may necessitate a greater clean-up depth. For example, where phytotoxicity to deep-rooted trees is a concern, clean-up to a depth of 2 m may be required. Also, the possibility of groundwater contamination or the presence of very high subsurface concentrations (which could result in future surface re-contamination) may indicate the need for even greater depths of clean-up.

4.2.6.2.1 Surface Sampling

The recommended protocol for surface and near-surface soil sampling (up to 30 cm depth) for verification of acceptable soil quality on a site is as follows:

- A minimum of 10 sites per hectare of land should be sampled. Suspected "hot spots" should be included; in other respects, the sampling grid should ensure that the sample sites are representative of the entire area.
- At each site, sampling should be conducted at depth increments of 0-5 cm, 10-15 cm and 25-30 cm, using a standard Oakfield sampler.
- At each site, samples should be collected from within a 2 m radius circle, with a minimum of 10 cores constituting the sample from each depth.

4.2.6.2.2 Depth Sampling

Verification sampling at depths greater than 30 cm requires the use of heavier equipment, which may not be readily available. Because of the overall difficulty of subsurface sampling, it is impractical and unreasonable to require the same degree of areal coverage as for surface soil sampling. In general, samples from below 30 cm depth should be collected from areas where deep-rooted trees may be planted, and from all locations suspected of having contamination at depth (i.e. hot spots). Where the concern is phytotoxicity, it is recommended that samples be collected from selected sites at depth increments of 85-100 cm and 185-200 cm. Additional samples of any odorous or stained soil also should be collected.

Aside from the suggestions re depth given above, no specific technique for sample collection is recommended. Whatever technique is selected (e.g. split spoon, open pit) care must be taken to ensure that samples from particular depth increments are not mixed with soil from other depths. Also, a composite sample consisting of 3 or 4 subsamples collected within the standard 2 m radius circle is preferred to a single sample, but it is recognized that other factors, both economic and site-specific situational, may be limiting.

4.2.7 Soil Radioactivity

The suspect soil should be sampled at a 0-5 cm depth over a 30 X 30 cm area using a shovel. Place the soil in a plastic bag with a number (LIS) and attach the name and address of the investigator to the bag. The sample should be delivered to a certified radiation laboratory

4.3 Snow Sampling

4.3.1 Site Selection

A snow sampling survey should be designed to provide an adequate number of sample points to cover the area considered to lie within the zone of contamination. Two control samples, remote from known source of pollution, are recommended for each investigation. Sample sites should be in undisturbed locations, away from roads or other local sources of contamination, sufficiently open to permit the free fall of snow, but not exposed to excessive drifting. It may also be desirable to establish collection sites near air quality monitors or precipitation samplers. A sketch map should be prepared for each site, with sufficient detail to enable the sample point to be relocated for future surveys.

4.3.2 Sample Collection

To avoid contamination from dead vegetation or other matter near the ground, snow sampling should preferably be undertaken only when total depth of snow cover exceeds 25 cm. For special studies, it may be desirable to undertake "event sampling", in which the complete profile of fresh snow from a single snowfall is collected. More commonly the profile of the entire snow cover is sampled. The case, the surface area sampled should be recorded. The quality of snow required from each location will depend on the kinds of parameters for which analysis are required. Generally, sufficient snow to yield 2 litres of meltwater is ample. Samples are collected with a clean, plastic, hollow cylinder, open at both ends, and free of metallic parts. The cylinder should preferably be of sufficient length to accommodate the total depth of snow expected on the ground. Cylinder diameter of about 15 cm, or somewhat larger, has been found suitable, although other convenient sizes would be equally acceptable. For snow of modest depth (up to 30 cm), a standard dustfall jar with bottom removed is a suitable sampling device. The cylinder is inserted in the snow to ground level.

Snow is then manually cleared from around one side of the cylinder and the cylinder lifted about 5 to 10 cm off the ground. A clean, hard, plastic device (e.g. toy shovel, dustpan, piece of plexiglass) is inserted under the base of the cylinder and the cylinder raised from the ground. The collected snow is transferred to a clean, heavy-gauge polyethylene bag and retained in unmelted condition until ready for processing. The number of cores obtained from each site is recorded, as well as the total depth of the snow, depth of fresh snow and the kind and amount of visible surface and subsurface contaminants. If available, meteorological records of recent snowfall (10-day period prior to sampling) may be useful in interpreting final results. To avoid loss of data and to assist in interpreting anomalous results, it is recommended that duplicate samples be collected at each site.

4.4 Sampling for Non-chemical Analysis Purposes

4.4.1 Pathology Diagnosis

The following field collection procedures will ensure that all samples collected for pathological investigation are received in the best possible form for symptom examination, isolation and identification.

- Select specimens to illustrate as completely as possible the various parts of the plant affected by the disease; whenever possible, roots, tubers, bulbs, stems, leaves, flowers and fruits should be collected.
- It is important that all plant material arrive at the laboratory in good condition with a completed field label and assigned number. Samples should be collected in perforated plastic bags (large or small) so as to minimize dehydration during transit and storage.

4.4.2 Nematode Diagnosis

Field sampling can give some knowledge of the nematode situation in a particular area. Sample collection for nematode diagnosis should include soil as well as plant root or shoot components, together with observations of related signs and symptoms (record in Phytotoxicology Investigation Notebook). Considerations for sampling should include the following:

- Time of sampling: Soil sampling in pairs is necessary for comparing nematode numbers and kinds in diseased vs healthy plants. The first sample should be from the vicinity of healthy plants (Figure 8). Collect 10-30 soil cores (using a soil tube, or small-bladed or garden shovel) to give a volume of about 500-1000 cm³ of soil. A similar second sample should be collected from stunted or debilitated plants in one or more areas in the field.
- Site Collection: Specific site collection of soil should be in the row for crops shown in Figure 8A. The collection of soil cores on perennial crops, such as ornamentals should be within the area of the drip line of the foliage shown in Figure 8B.
- Depth: The depth of soil cores should be the rooting zone, generally the upper 15-20 cm of soil. Deep-rooted plants, such as fruit crops or ornamentals may require sampling depths as great as 1 meter.

4.4.3 Insect Pest Diagnosis

Investigators who wish to collect samples for insect pest diagnosis should familiarize themselves with the following information.

Equipment: The equipment used in collecting insects and other arthropods for diagnosis includes such items as insect net, killing bottle, suction bottle and tweezers.

Insect Net: The insect net is used for catching flying insects and for sweeping insects from vegetation. The standard insect sweep net shown in Figure 9 is essentially a fine cloth bag hung from a 35 cm loop attached to a 1-metre handle. The bag net is cone shaped and is approximately 60 cm deep. When "sweeping" with the net, tilt the lower rim of the net so it is 4 to 5 cm in advance of the upper rim to catch insects which drop from the plants. Keep the net below the tops of the plants or branches until the end of the sweep. A single sweep consists of one 180° arc taken as you step forward shown in Figure 10. To make natural swings and conform to this pattern, swing your body from side to side as you sweep. Raise the net at the end of each sweep and reverse the direction of your swing to re-enter the herbage. Sweeps may be taken singly or consecutively.

Killing Bottle: A killing bottle is a screw cap glass jar (125 ml) to which is added 70% alcohol. The alcohol will preserve many types of insects but insects (especially moths and butterflies) to be placed in the herbarium should not be immersed in alcohol.

Suction Bottle: The suction bottle, or aspirator shown in Figure 11 is a device for collecting small insects from the net or directly from under stones or bark.

Sweeping: Sweep the herbage, the flowers or the foliage of trees with rapid side-ways strokes of the net. The specimen caught can be picked from the net with your finger, fine-pointed forceps or an aspirator. Capture nocturnal flying insects with a net or killing bottle as they fly around the light or rest nearby, or use traps or baits that capture and hold them as they approach the light.

Baits and Traps: Natural baits are flowers, aphid secretions (honeydew), the fermenting sap that exudes from wounds in trees, rooting or overripe fruit, animal excreta and rotting fungi. A jar, tin can or plastic (wax paper) cup can be used as a pitfall shown in Figure 12 to catch beetles and other insects that crawl on the surface of the ground. Bury the container to its rim in the soil. Put a piece of wood or a flat stone over the mouth of the pitfall to keep out rain water, but leave enough space for insects to enter. Suspend the bait in the can or jar in a cheese cloth bag from a stick. Place a solution of equal amounts of water and acetylene glycol below the bait. The solution drowns the insects and prevents their decomposition for at least a week.

Funnel Bait Trap: A funnel bait trap can be used for catching flying insects (Figure 13). The bait is placed in the pan and the insects enter through the opening below the cylinder. When they feed, they fly upward and pass through the opening at the apex of the cone into the container.

"Sugar" Bait: This bait could be used for Lepidoptera. "Sugar" is a form that has been partly fermented. The mixture consists of brown sugar molasses to which stale beer is added. Mashed bananas, overripe peaches or fermenting fruit juices could be included, amyl acetate may be added. The mixture must be aromatic, giving off odours and thick enough not to run off or soak in to the trunks of the trees to which it is applied. Apply the mixture with a brush to tree trunks and visit the site at intervals after dark when the moths and other insects can be found imbibing. Paint a patch of the mixture (about 10 X 15 cm) on each tree trunk at a convenient height on the side away from the wind. The moths usually fly outward and downward when disturbed or they simply drop to

the ground. The method of catching a specimen is to hold an open bottle or a net immediately below it and move the bottle or net up slowly until it touches the insect. Insects feeding at "sugar" patches often become sluggish, probably because of the effects of the alcohol.

Baited Traps: Insect larvae, such as Gypsy moth can be trapped as they descend the trees to hide during the day. The traps consist of a strip of burlap about 30 cm wide that is tied around the tree trunk with a strip cord. The top half is then folded over the bottom half. The descending larvae take shelter under the strips and are easily captured. The traps are inspected from time to time during larval feeding period. The larvae are then collected.

Beating: Hit a branch of a tree or shrub hard enough with a heavy stick so that the anthropoids fall in the tray or sheet below, where they are easy to see and capture. Use a downward stroke to strike a branch.

Instead of a beating stick and sheet, a screen beating tray (Figure 14) is more effective for beating small anthropoids, particularly mites, from foliage. Rather than striking the branches with a stick, strike the branches two or three times against the upper screened surface of a white enamel or plastic tray. The specimens fall through the screen to the surface of the tray and the screen prevents excessive fragments of leaves and debris from cluttering the tray. Immediately after you have finished beating, remove the screen and examine the white surface of the tray for tiny moving specimens which can be collected either with an aspirator or a fine artist's brush moistened with alcohol.

Leaf Mining Insect: Some species of larvae of Lepidoptera, Diptera, Hymenoptera and Coleoptera feed within the leaf, needle, petiole and cuticle of plants - they are leaf miners. Collect an adequate amount of representative injured material together with the insects found on or in the vicinity of the injured tissues.

Batches of eggs or immature eggs of the insect occurring on a single plant should be collected. Other life stages such as larvae, pupae and the products of insects, fecal pellets (frass) silk in the case of caterpillars, honeydew, etc. are also very useful for identification purposes.

4.4.4 Histology Diagnosis

Sample Collection Procedures

The following important points are suggested to all when collecting samples for histological observation.

- Select very typical specimens which represent the injury that you are investigating. Although very little plant material is required, the sample should be typical. Specimens should include all stages of symptoms (incipient, medium and severe) of injury observed in the field.
- Specimens for "control" purposes must be collected. These should include samples from healthy plants remote from the affected area.

4.4.5 Herbarium Preservation

The following is a condensed guide to collecting plant material in the field to ensure good specimens for identification and herbarium preservation. Complete details on pressing, drying, labelling and mounting are outlined in the Ontario Ministry of the Environment Phytotoxicology Laboratory Manual and Herbarium Procedures Manual.

- a) In collecting small herbaceous plants, the whole plant should be collected including inflorescence (if present) and roots, keeping in mind the size of the herbarium sheet (30 X 45).
- b) With larger plants, trees and shrubs, 25-30 cm long samples should be taken from the end of the plant or branch with several leaves intact and showing terminal and lateral buds, flowers and fruits.
- c) In collecting, care should be taken to select a good representative specimen which illustrates exactly what you want and what others will be able to identify.
- d) When collecting samples of injured plants, always include adequate material, either less injured or uninjured for positive identification of the host.

5 LABORATORY METHODS

5.1 Sample Preparation

5.1.1 Vegetation Samples

5.1.1.1 Temporary preservation in the field

The rate of deterioration of any sample will increase following collection. Any adverse conditions can cause this rate of deterioration to progress so rapidly that some samples can be destroyed in a matter of minutes. The most common problems encountered are direct sunlight, excessive heating and excessive moisture. These problems can be eliminated by keeping samples shaded and cool, preferably in a cooler outfitted with ice-packs or a mechanical cooling device. Perforations in plastic bags will prevent build-up of excess condensation or hot air.

Samples which are to be analysed for certain non-routine analysis must be frozen. This includes analysis of enzymes, pigments and certain other properties. Arrangements for this should be made with the processing laboratory prior to collection to obtain appropriate collection vessels.

The fresh samples should be placed in the refrigerator.

5.1.1.2 Transporting vegetation samples to the processing laboratory

To maximize the quality of plant samples, they should be kept in transit for the shortest possible period of time. During that time they should be kept cool and away from bright sunlight to reduce spoilage. Picnic coolers with ice-packs or fitted with mechanical coolers are recommended. Properly maintained samples can retain their condition for up to about one week.

5.1.1.3 Processing of Not-Washed Vegetation Samples

The vegetation samples which are not to be washed are placed individually in Kraft paper bags.

The NW (not washed) gummed label is stapled to the paper bag and the sample number is written on the outside of the bag.

The sample is dried for a minimum of 36 hours at 80C in a forced air oven. Large samples and samples with a high moisture content may require longer periods.

Once dried, the sample is ground in the Wiley Mill (See Section 4.15).

The sample is stored in 125ml glass jars.

The larger part of the gummed label is placed on the corresponding sample jar. The smaller numbered label is placed on the lid of the jar. To ensure against loss of the label, a piece of transparent adhesive tape is wrapped around the jar to cover the label.

5.1.1.4 Processing of Washed Vegetation Samples

5.1.1.4.1 Washing Procedure

The sample of vegetation to be washed is placed in a large, clean Pyrex crucible.

The W (washed) gummed label is stapled to a paper bag and the sample number is also written on the outside of the bag.

Disposable polyethylene gloves are worn during the washing process.

1 litre of soap solution is added to the crucible containing the sample and gently washed by hand for 30 seconds. (See Section 4.12 for preparation of soap solution.)

The soap solution is decanted from the crucible and discarded. Care must be taken to avoid loss of any of the sample.

The sample is then rinsed with 1 litre of distilled water for 10 seconds. This is repeated until the sample has been rinsed a total of 3 times in distilled water.

The sample is well drained and placed in the corresponding numbered paper bag.

The sample is dried for a minimum of 36 hours at 80C in a forced air oven.

Once dried, the sample is ground in the Wiley Mill (see Section 4.15).

The sample is stored in 125ml glass jars.

The larger part of the gummed label is placed on the corresponding numbered sample jar. The smaller numbered label is placed on the lid of the jar. To ensure against loss of the label, a piece of transparent adhesive tape is wrapped around the jar to cover the label.

5.1.1.4.2 Preparation of Washing Solutions

Washing procedures for vegetation are intended to remove surface deposits of air contaminants. To aid in this process, different soaps may be used to wet the sur-

face of the samples. The problem associated with the use of soaps is the residues which may be left on the samples. Depending upon the analysis, the soaps can be altered to avoid contaminations of the sample by certain elements. It is therefore important to know the analysis requested by the investigator. The standard washing routine uses the mixture of EDTA and Alconox.

Preparation of Standard Washing Soap solution

Add 30g of EDTA and 30g Alconox to approximately 1 litre of distilled water.

Heat solution for several minutes until material is completely dissolved. (Set heater at 4 and mixing bar stirrer at fast).

Add solution to 59L distilled water in soap tank in laboratory. The final washing solution should contain 0.05% EDTA and 0.05% Alconox.

Stir thoroughly.

5.1.1.4.3 Preparation of Alternative Soap Solutions - Sulphur Analysis

For samples requiring sulphur analysis, Alconox can not be used. In this case, Ivory Snow detergent is substituted for Alconox in step 4.12.1.1.

Repeat steps in 6.1.1.4.2

5.1.1.4.4 Distilled Water Washes

No soaps are added to the wash water in step 4.12.1.1 hence the wetting activity of this procedure is less effective. Only water soluble materials will be removed from the leaf surface.

5.1.1.4.5 Dilute Acid Washing Solutions

Add 500ml of 1 NHCL to 9.5 litres of distilled water (or 50ml to 950ml distilled H₂O) to produce a 0.05 NHCL acid solution. This replaces the soap solution in step 4.11.4. Care should be exercised in using this procedure since it could accelerate the leaching of elements internal to the samples, as well as increase the Cl content of the prepared sample.

5.1.1.4.6 Organic Solvent Washes

In certain cases, it may be convenient to remove contaminants from plant foliage samples by stripping away the entire cuticular layer from the leaf surface. This can be done by dissolving the cuticle in an organic solvent such as chloroform.

- place 5g of foliage in Erlenmeyer flask.

- Add 50ml of chloroform to flask (corresponding volume changes are made for different weights of sample).
- Swirl flask for 10 seconds and pour into Buchner funnel.
- Retain chloroform wash if analysis are to be performed on residue removed from leaf surface.
- The W (washed) gummed label is stapled to a paper bag and the sample number is also written on the outside of the bag.
- The foliage sample is removed from the Buchner funnel and placed in the paper bag.
- The sample is dried for a minimum of 36 hours at 80C in a forced air oven.
- Once dried, the sample is ground in the Wiley Mill (see Section 4.11).

CAUTION: Due to the potential hazards associated with chloroform, extra care and precautions must be observed. These include:

All work must be done under the fumehood.

Disposable polyethylene gloves and lab coat must be worn.

A respirator equipped with an organic vapor cartridge must be worn.

Other staff must be alerted to the activities about to be performed.

Air quality sampling in the laboratory must be performed during the course of the washing procedure. Results must be recorded.

5.1.1.4.7 Preparation and Washing Edible Vegetables and Fruits

Fresh fruits and vegetables often have been in contact with soil or pesticide residues etc., and have their surfaces contaminated with these materials. It is extremely difficult to be certain that any wash procedure will remove this surface contamination. The position adopted by the Phytotoxicology Section is that anyone preparing this food for consumption would have at least the same difficulty washing the produce therefore it is most realistic to treat the produce on an "as consumed basis". This means essentially washing the plant material in tap water to remove visible residues.

All samples consisting of above ground exposed plant parts including leaves, stems, floral parts, fruits and edible fruit pods are hand washed and rinsed under running tap water. Hand rubbing only is allowed until the sample is visibly clean. There is no time limit on this procedure.

All samples consisting of below-ground plant parts including roots, bulbs and tubers are thoroughly with a vegetable brush under running tap water until visibly clean. Special care is taken to remove adhering soil particles. After scrubbing, give additional rinse in tap water. There is no time limit on this procedure.

For all unexposed plant parts such as seeds, kernels, fruit and vegetable where the outer skin is not edible (i.e. squash, pumpkins, melons) the samples are washed to remove surface contaminants under running tap water. They are then peeled and the inedible portions discarded. The edible portions are then rinsed under running tap water.

Large portions of vegetable and fruits should be cut into smaller sections. This facilitates drying as well as making it possible for the sample (which can become extremely hard on drying) to pass into the Wiley Mill grinding chamber.

Samples with high water content such as tomatoes can not be placed in paper bags since the juice will soak into the paper and weaken the bag. Instead the sample is placed in beakers for drying. The gummed label is attached to the beaker with a spring clip.

The sample is placed in a forced air oven at 80C until dry.

Once dried, the sample is ground in the Wiley Mill (see Section 4.15).

5.1.1.4.8 Grinding of Vegetation in the Wiley Mill

The ventilating system is turned on above the grinders.

The majority of routine grinding of vegetation samples is accomplished using a large Thomas Wiley Mill.

The door to the mill is closed by swinging the latch into the engaged position and the knob on the front of the door firmly tightened to push the door tightly against the outer rim.

A small plastic bag is placed on the outlet from the grinder and held in place by an elastic band.

The power to the motor is turned on by engaging the safety lock mechanism and turning on the power switch.

The dried vegetation sample is inserted into the funnel-shaped hopper at the top of the grinder. The sample is pushed into the grinding chamber using the wooden plunger. Judicious use of the plunger will minimize the loss of sample material being thrown out through the hopper, thereby reducing nuisance dust. Also samples consisting of hard materials (i.e. wood, dried roots, etc) can be kicked back on occasion and the plunger can help to guard against this.

The grinder is switched off and the plastic bag is removed. A 125ml glass jar is screwed into the threaded portion of the outlet at the bottom of the grinder. The ground sample in plastic bag is roughly mixed and passed through the grinder for a second time. A full jar is collected and the excess material is discarded. If the dried sample is small and can be mixed in the jar, then the sample need only pass thorough the mill once directly into the jar.

The jar is labelled as outlined in 4.10.11. It is good practice to label the jar before attaching it to the grinder.

The Wiley mill is thoroughly cleaned between samples to avoid cross contamination of samples.

The door is opened after the rotor and blades have stopped moving. The door is cleaned to remove any plant material using a vacuum cleaner and large paint brushes.

The outlet attachment at the base of the chamber is removed by loosening the large screw knobs under the grinder chamber. The grinder screen, support and outlet funnel are all brushed and vacuumed clean.

The inner portion of the grinding chamber and blades are carefully cleaned with brush and vacuum. Great care must be taken at this stage to avoid pinching of fingers between the rotating and stationary blades.

Certain plant samples contain resins which coat the interior of the grinder. These can frequently be removed with the assistance of an alcohol wash.

The grinder is reassembled in preparation for the next sample.

The size of the powder produced can be controlled by utilizing various screen mesh sizes. Normally, the screen opening size is 1mm in diameter.

To minimize the problem of dust exposure during the grinding process, dust masks and laboratory coats should be worn.

5.1.1.4.9 Grinding of Vegetation Using Liquid Nitrogen

Certain types of samples pose problems for grinding using the Wiley Mill procedure. These include samples with high sugar and oil content and do not form a dry powder (usually paste) when ground in the Wiley Mill. To overcome this problem, the samples can be made very brittle at very low temperatures and can be more easily broken in this condition.

Prepare and oven dry samples as described in 4.9 and 4.10 above. Alternatively, the samples could be freeze dried. For certain procedures, fresh material may be ground in liquid nitrogen as well using the same following techniques, however, the investigator must be aware that the final product is a paste and not a powder.

Mortars and pestles (50ml) of high quality porcelain should be chilled in the freezer and then on dry ice in a dry ice bucket. Samples should also be chilled to reduce loss of nitrogen. Similarly, the dewar flask should be cooled in the freezer to minimize evaporation of liquid nitrogen at the initial fill up.

Add small amounts of liquid nitrogen to pestle until boiling stops.

Add a small amount of sample to liquid nitrogen in pestle and allow to cool until boiling stops.

Gently crush sample in liquid nitrogen.

Carefully and slowly add more liquid nitrogen if necessary. Slowly grind sample with mortar in pestle until dust-like texture is attained.

Pour mixture into a beaker and allow liquid nitrogen to evaporate. Transfer the sample to 125ml glass jar and label (see 4.9.6).

Be sure to maintain mortar and pestle in dry ice bucket to reduce possibilities for warming and shattering. This also prevents condensation of moisture from air on the equipment.

Immediately seal glass jars to prevent condensation of water on sample surface.

Clean mortar and pestle with a brush.

Due to the hazards associated with the cold temperatures of liquid nitrogen, certain safety precautions must be observed. These include the use of insulated gloves, goggles and lab coats.

5.1.2 Processing Soil Samples

5.1.2.1 Transporting of Soil Samples

To maximize the quality of soil samples, they should be kept in transit for the shortest possible period of time. During that time they should be kept cool and away from bright sunlight to reduce heating.

5.1.2.2 Processing of Soil Samples for Chemical Analysis

The entire contents of each sample container is spread out on clean, non-metallic trays. (This does not apply to samples collected for organics analysis purposes.)

The trays are placed on open shelving units and the soil is allowed to air dry at room temperature ($22^{\circ}\text{C} \pm 2^{\circ}\text{C}$) for at least 48 hours.

Under a fumehood, the entire sample is broken up using a wooden mallet and any twigs, rocks, stones etc., are removed and discarded.

The entire sample is then sieved through a 2mm sieve to obtain the soil fraction. Any material retained on the sieve is discarded.

A sub-sample of the less than 2mm fraction is taken (usually enough to fill a 125 ml sample jar) and the excess sample is discarded.

The sub-sample is further disaggregated by hand using a mortar and pestle or by the mechanized soil grinder. The entire sub-sample is ground until it passes through a No. 45 mesh ($< .355\text{mm}$) sieve.

The sample is then stored in a 125ml glass jar.

5.1.2.3 Processing of Soil Samples for pH Determination

pH measurements have been done traditionally using distilled water since this is the easiest method. If a study has used this method in the past, this practice is normally continued.

Place about 10g of the $< 2\text{ mm}$ fraction air dried soil in a 50ml beaker or a disposable paper or plastic cup.

Add 20ml distilled water and stir soil suspension.

Shake on a reciprocating shaker (low speed) for 30 min.

Let soil suspension stand for at least 1/2 hour, but no more than 5 hours.

Measure the pH of the soil sample according to the instrument manufacturer's directions. A second extraction/measurement should be conducted on selected samples to establish error limits.

5.1.2.4 Processing of Soil Samples for pH Determination in CaCl₂ Solution

The determination of soil pH in CaCl₂ solution provides the most accurate measure of the soil pH to which the plant root is exposed. This is the method of choice and should be performed unless otherwise directed.

All steps in the procedure are the same as those for pH determination in distilled water with the exception that a 0.01M calcium chloride solution is substituted for distilled water.

Preparation of Calcium Chloride Solution

Calcium chloride stock solution (3.6M)

Dissolve 1,059g of calcium chloride in distilled water and dilute to 2 litres (or 529.5g in 1L).

Calcium chloride working solution (0.01M)

Dilute 50ml of the above stock solution to 18 litres with distilled water (or 5ml to 1.8L). The pH should be between 5.0 and 6.5, if it is not, adjust with either calcium hydroxide or hydrochloric acid as required.

5.1.2.5 Processing of Soil Samples for Conductivity Determination

Conductivity may be used to provide information on salinity measurements of soil solutions, leachate quality and the inertness of industrial waste or "clean fill". The sample extract is introduced into a jacketed conductivity cell and the conductivity read on a suitable meter. The measured electrical resistance is a function of the electrolyte concentration and hence salt concentration of the solution.

Weigh 15g of 2 mm AIR-DRIED soil into a clean, large test tube.

Add 30ml of distilled water and stir suspension.

NOTE: Weights of soil are arbitrary but soil:water ratio should be maintained at 1:1, 1:2 or 1:5. The specific ratio used must be recorded.

Shake mixture for 30 minutes on a reciprocating shaker at low speed.

Measure the soil conductivity according to the instrument manufacturer's directions. A second extraction/measurement should be conducted on selected samples to establish error limits.

5.1.2.6 Ammonium Acetate Extract Procedures for Soil

Many types of extractant solutions have been used to estimate the portion of the soil element pool that is available for uptake by plant roots. Some techniques are more appropriate than others for given situations; however, the use of ammonium acetate is the most commonly used.

Weigh 5g of <2mm air-dried soil into a 50ml centrifuge tube.

Add 25ml of 1N ammonium acetate.

Shake on reciprocating shaker (low speed) for 10 to 15 minutes.

Let tubes stand overnight.

Centrifuge (laboratory bench-type centrifuge) samples at medium speed for 5 minutes.

Filter extracts through Whatman 42 filter paper into a 100ml plastic vial.

Add 25ml 1N ammonium acetate to soil cake and put tubes on reciprocating shaker (low speed) for 10-15 minutes.

Pour through same filter paper (above) into plastic vial.

Bring volume to 50ml using fresh ammonium acetate. (This gives a 10X dilution of original sample).

Preserve metals in solution by adding 2 drops of concentrated HNO_3

Preparation of 1N ammonium acetate solution.

Weigh out 77.08g of $\text{CH}_3\text{COONH}_4$.

Dissolve in small quantity of distilled water using stirrer if necessary.

Bring volume up to 1 litre with distilled water and cover.

Deliver to analytical laboratory for immediate analysis.

Calculations

Available Concentration element = of element in x 50 ml in ug/g
extract (pg/ml) solution
soil 5g soil

5.1.2.7 Hot Water Soluble Extract Procedure for Soil

The hot water extract procedure is recommended for available boron determination. Other tests can also be performed with the understanding that this particular method for extraction has been employed.

Weigh 20g of 2mm AIR-DRIED SOIL into a 100ml beaker.

Add 40ml of distilled water and stir suspension.

Cover beakers with watch glass and heat slowly on a HOT PLATE to boiling. THEN REMOVE.

Filter extract through Whatman No. 42 filter paper.

Let filtrate cool (approximately 1 hr), and pour into a 100ml plastic vial and adjust to 40ml (hot water could damage plastic vials).

Deliver to analytical laboratory for immediate analysis.

5.1.2.8 Acid Extractable Metals from Soil

This procedure is designed to determine the quantity of extractable metal cations attached to the clay and organic constituents of a soil. Extractable metals are defined as those metal cations that can directly interact with the soil solution.

Extraction of metal cations depends on the extracting solution selected. The extractant selected for this standard operating procedure is 0.1N HCl.

Weigh 5.0g of <2mm air-dried soil into a 250ml Erlenmeyer flask.

Add 100ml of 0.1N HCl extracting solution.

Cap Erlenmeyer flasks with parafilm and shake vigorously for 1 hour on a mechanical shaker. Be sure shaking action is sufficient to have extracting solution in contact with entire sample. Failure to meet precision guidelines in the Data Quality Objectives table may result because of poor shaking technique.

Remove flasks from shaker and let stand for 30 minutes to allow suspension to settle.

Filter through No. 42 filter paper and collect in acid washed (1N HN03) polyethylene vial.

Note: All calculations will be based on 100ml extracting solution volume. Quantitative recovery of all extracting solution in filtration step is not necessary.

Filtrate can be stored at room temperature, but it is recommended that analysis be completed as soon as possible and that filtrate be refrigerated.

5.1.3 Processing Of Mossbag Monitors

The mossbags which are not to be washed are placed individually in Kraft paper bags.

The mossbag is dried for a minimum of 36 hours at 80°C in a forced air oven.

After drying, carefully open the paper bag and cut open the mossbag screen with scissors.

The moss is ground in the a Wiley Mill.

The ground sample is collected directly into a 125ml glass jar.

After each sample is ground, the Wiley Mill is thoroughly cleaned using a vacuum cleaner and brush. The same cleaning principles as for the large Wiley Mill are used, suitably modified to the characteristics of the smaller machine.

5.1.4 Snow Samples

Occasionally snow sampling is a useful means of assessing atmospheric inputs of contaminants into the terrestrial environment.

Samples are normally delivered in a frozen state in polyethylene bags. They are kept in the freezer until the melting process is initiated.

In the frozen state, the sample can be quite hard and can cause perforations to the sample bag if it is allowed to strike against another object including the bench top, floor or even another sample. The perforation will allow leakage from the bag and the sample could be lost. This can be corrected by transferring the sample to a clean polyethylene bag in the laboratory. An alternative is to place the sample and bag together in a new bag.

The snow-filled bags are placed in clean, plastic pails (pre-rinsed with distilled water) and melting is allowed to proceed at normal indoor temperatures. If plastic pails are not available, then the samples should be placed where drainage from any bag which might leak does not constitute a problem (i.e. on stainless steel counter with drain).

After samples have melted (usually 12-18 hours) the melt water is examined for particulate residue. Observations regarding any residue are recorded.

Bags are shaken manually to ensure uniform distribution of particulate matter in the meltwater.

The contents of each bag are then poured into graduated cylinders (1L size) and the meltwater volume noted and recorded to nearest 10ml.

A small aliquot is taken for pH measurement, which is recorded.

The number of aliquots into which each meltwater sample is divided will depend on the kind of analysis requested and the sample preservation treatment prescribed for each analysis.

The preserved samples are placed in appropriate glass or plastic bottles.

Samples are stored in the refrigerator at 40C until they are delivered to the analytical laboratory.

5.1.5 Miscellaneous Techniques

9.1 Procedure for Measurement of Moisture Content

This procedure is designed to determine the moisture content of materials such as soil or vegetation for expression of results on an oven-dry basis. Consideration of factors such as original material water content (i.e. air-dried vs. fresh soil) should not be overlooked.

Clean an evaporating dish and dry it for two hours at 100C. Allow the dish to cool in a desiccator. Weigh the dish and record the weight to nearest 0.01g.

Transfer 5-10g of sample into a pre-weighed dish. Solid samples may first have to be broken up with a spatula in order to obtain a representative aliquot. Semi-solid samples must be stirred with a spatula prior to sampling in order to homogenize them.

Weigh the dish and sample immediately to avoid loss of moisture.

Record weight of dish plus wet sample to nearest 0.01g.

Place the dish plus wet sample in the oven at 105°C for a minimum of 16 hours.

Remove the dish from oven and allow to cool in a desiccator for 2 hours.

Remove the dish plus dried sample from the desiccator and weigh immediately to avoid moisture absorption.

Record the weight of dish plus dried sample to nearest 0.01g.

Repeat steps 9.1.5 to 9.1.8 to ensure that a stable dry weight has been attained.

5.2 Suggested Analytical Methods

(to be added)

6 INTERPRETATION OF ANALYTICAL RESULTS

6.1 Upper Limit of Normal Contaminant Guidelines - Derivation and Significance

A table of "Upper Limits of Normal Contaminant Guidelines" is under continuing review in the Ministry of the Environment and will be expanded and revised as more data become available. The current list is published in the Ministry document "Ontario Ministry of the Environment 'Upper Limit of Normal' Contaminant Guidelines for Phytotoxicology Samples"; publication number ARB-138-88-PHYTO.

The MOE "upper limit of normal" contaminant guidelines represent the expected maximum concentrations of contaminants in surface soil (non-agricultural), foliage (deciduous and current year coniferous trees and shrubs), grass, moss bags and/or snow, from areas of Ontario not subject to the influence of point sources of emissions. "Urban" guidelines are based upon samples collected from centres of minimum 10,000 population. "Rural" guidelines are based upon samples collected from non-built-up areas. Samples were collected by MOE personnel using standard sampling techniques as described in this Appendix. Chemical analyses were performed by the MOE Laboratory Services Branch.

The guidelines were calculated by taking the arithmetic mean of available analytical data and adding three standard deviations of the mean. For those distributions that are "normal", 99% of all contaminant concentration results for samples from "background" locations (i.e. not affected by point sources nor agricultural activities) will lie below these upper limits

of normal. For those distributions that are "non-normal", the calculated upper limits of normal will not actually equal the 99th percentile, but nevertheless they lie within the observed upper range of MOE results for Ontario samples. Geometric means were not employed in calculating the guidelines because: 1) tests of two representative non-normal distributions showed that normality was not significantly improved by using log-transformed data, and 2) the guideline concentrations calculated using the geometric mean were considerably higher than the maximum observed concentrations.

It is stressed that these guidelines do not represent maximum desirable or allowable levels of contaminants. Rather, they serve as levels which, if exceeded, would prompt further investigation on a case by case basis to determine the significance, if any, of above-normal concentration(s). Concentrations which exceed the guidelines are not necessarily toxic to plants, animals or man. Concentrations which are at or below the guidelines would not normally be considered toxic. A brief review of world literature has shown that the guideline concentrations are generally within the ranges of results reported by other investigators.

The table of guidelines is under continuing review and will be expanded and revised as more data become available. The current list is published in the Ministry document "Ontario Ministry of the Environment 'Upper Limit of Normal' Contaminant Guidelines for Phytotoxicology Samples"; publication number ARB-138-88-PHYTO.

6.2 Soil Conductivity

Analytical laboratories occasionally conduct soil electrical conductivity (total salts) measurements on a 2:1, water:soil suspension (EC₂). However, most literature studies of salt phytotoxicity have measured soil conductivity on the soil saturation extract (EC_e). Conductivity measurements differ significantly depending on which technique is used, with EC₂ readings generally being several times lower than EC_e readings. Unfortunately, the relationship between the two values varies considerably depending on the type of soil and the nature of the soluble salts present.

The M.O.E. decommissioning guidelines (in: "Guidelines for the Decommissioning and Cleanup of Sites in Ontario") suggest maximum allowable EC_e levels of 2 millisiemens/cm (2 mS/cm) for residential land use and 4 millisiemens/cm (4 mS/cm) for industrial land use (note: 1 siemen = 1 mho). These guidelines are not applicable to measurements made using a 2:1, water: soil suspension.

Table 9: Soil Conductivity Reading Interpretation

Conductivity "Salt" Reading millisie- mens/cm	Rating	Plant Response
0-0.25	L	Suitable for most plants if recommended amounts of fertilizer are used.
0.026-0.45	M	Suitable for most plants if recommended amounts of fertilizer are used.
0.46-0.70	H	May reduce emergence and cause slight to severe damage to salt sensitive plants.
0.71-1.00	E	May prevent emergence and cause slight to severe damage to most plants.
1.00	E	Expected to cause severe damage to most plants.

For greenhouse soils the OMAF soil test uses a larger soil sample and measures conductivity on a saturation extract. For greenhouse crops using that method, conductivity readings up to 3.5 millisiemens/cm are acceptable.

APPENDIX 11

QUALITY ASSURANCE FOR THE CLEAN AIR PROGRAM

QUALITY ASSURANCE FOR THE CLEAN AIR PROGRAM

In this Appendix, the general quality assurance requirements under the Clean Air Program (CAP) are discussed. Detailed guidance on how to conduct performance and system audits of air monitoring systems will be available from the Ministry. These general principles will apply to:

Continuous ambient air monitoring activities
Continuous (source) emission monitoring (CEM) activities
Discrete ambient air monitoring activities
Discrete source emission monitoring activities

In conjunction with Appendices 9 and 10 of the Clean Air Program (CAP), proponents must submit a quality assurance and quality control program and program rationale to the Ministry. Proponents are required to perform the following:

1. Proponents are required to obtain periodic independent audits of their monitoring program according to Ministry guidelines and procedures in Section A of this Appendix. The Ministry requires that any organization performing the independent audit functions must submit to the Ministry proof of its independence and competence.
2. Proponents are required to notify the Ministry immediately on any variance with respect to the approved monitoring program.
3. Proponents must maintain accurate, complete and current records of maintenance and operation related to the monitoring program as required under the Ministry guidelines and procedures in Section B.
4. Proponents must maintain accurate, complete and current audit and calibration records according to prescribed Ministry guidelines and procedures in Section C.
5. Proponents must provide proof of the integrity of the data acquisition system (or method) and data storage according to Ministry guidelines and procedures in D below.
6. Proponents shall submit to the ministry reports on QA/QC activities and air quality data as instructed and as required by the Ministry according to Ministry guidelines and procedures in Section E.
7. Proponents must provide adequate accessibility to all pertinent facilities and monitoring equipment to permit safety auditing of the monitoring program. In addition adequate utilities such as sufficient heat, light and hydro outlets must also

be provided to permit the running of calibration equipment as well as enough space in a relatively clean working environment to carry out performance audits and possible inspections by Ministry personnel.

- A. The Ministry requires proponents to obtain independent "performance" and "system" audits of their respective monitoring programs for the purpose of ensuring the integrity of the monitoring program.

An independent system and performance audit must demonstrate an arms-length operational, managerial and financial relationship between the auditor and the proponent. Proof of competence consists of, but is not limited to the following; staff qualifications, relevant experience and credibility of the organization, suitable physical facilities and instrumentation and an acceptable internal quality assurance plan.

A "performance audit" is defined as a "quantitative analysis" or check with a material or device with known properties or characteristics. A "performance audit" is performed by a person different from the routine operator/analyst and using standards and audit equipment physically different from the regular calibration equipment used by the operator/analyst. Such audits are conducted periodically to check the accuracy of a project measurement. For some performance audits it may be impractical or unnecessary to have a different person then the routine operator/analyst carry out the audit. In these cases the routine operator/analyst must not know the concentration or value of the audit standard until the audit is completed. The other conditions of the audit must still be met that is, the audit standards be physically different from the calibration standards and the audit device physically different from the calibration device.

A "system audit" is defined as an on-site "qualitative" review of facilities, equipment, training, procedures, record keeping, data validation, data management and reporting aspects of the total (QA) system. This is done to arrive at a measure of capability of the measurement system to generate data of the required quality and/or to determine the extent of compliance of an operational QA system to the approved QA project plan. The required frequency of both "performance" and "system" audits depends on the scope of each air monitoring program as defined in Appendix 10 (The audit details with respect to the different air monitoring programs will be developed later.)

- B. Proponents must maintain accurate, complete and current records of maintenance and operation related to the monitoring program. The benefit of such activities will increase the measurement system's availability and thus increase data completeness (i.e. percent valid data). In addition, the quality of the data should improve as a result of good equipment operation.

Continuous pollutant analyzers (ambient and source emission) commonly require daily service checks (see also Appendix 9). The daily service checks, preventive maintenance and routine calibrations should be integrated into an internal quality control schedule. These records should be maintained for scrutiny by the auditors and supervisors in a bound operational and maintenance record logbook. In addition, records should be kept of equipment reliability (breakdowns and unscheduled maintenance) for the purpose of coordinating and assessing the overall equipment maintenance program, as well as validating the air quality data. The operational and maintenance record logbook is stored at the sampling site with a duplicate copy kept by the supervisor for review and filing.

- C. Proponents must maintain accurate, complete, and current audit and calibration records. "Calibration" is the single most important operation in the measurement process. A "calibration" is defined as the process of establishing the relationship between the output of a measurement process and a known input. Often a calibration also includes making a physical adjustment to an instrument to make it agree with known standards after the original relationship has already been established. Calibrations, (as opposed to audits) are usually performed by the operator/analyst on a routine basis.

Proponents must develop and implement a calibration plan and an audit plan for all data measurement equipment and calibration standards. The calibration plan must include:

- 1) a statement of the maximum allowable time between multipoint calibrations and/or routine calibration checks;
- 2) A complete list of calibration standards to be used;
- 3) A statement of the minimum quality or accuracy of the calibration standards, (e.g., Standards should have four to ten times the accuracy of the instruments that they are being used to calibrate);
- 4) Provisions for standards traceability. Secondary standards should be traceable to NBS-SRMS (the National Institute for Science and Technology formerly the National Bureau of Standards) or commercially available certified reference materials (CRMS) if available;
- 5) A statement of proper environmental conditions to ensure that the equipment is not significantly affected by its surroundings;
- 6) A statement of proper operating conditions to ensure that the equipment is being operated according to, and within, the manufacturers specifications;
- 7) Documentation on qualifications and training of personnel or operator/analyst performing the calibration; and,
- 8) Provision for proper record keeping and record forms to ensure that adequate documentation of calibrations is available for use in internal data validation and system audits.

Items that should be recorded for each instrument calibration include:

- 1) a description of the calibration material/device including the serial number;
- 2) a description of the instrument calibrated, make, model number and serial number;
- 3) the instrument location, site number or station number;
- 4) the date and time of the calibration;
- 5) the signature of the person performing the calibration; and,
- 6) the calibration data (results), including the environmental conditions during the calibration.

The calibration records should be kept in bound calibration logbooks.

Proponents must also keep records of the "performance" and "system" audits performed by independent auditors as required under schedule 19, part 1. And to submit them as part of the "performance system and audit report" required under schedule 19, part 6.

The "performance audit" report must include the following.

- 1) assessment of the accuracy of the data collected by the audited measurement system;
- 2) identification of any sensors out-of-control, non-functioning and/or not running according to performance specifications;
- 3) identification of monitoring network bias; and,
- 4) measurement of improvement or non-improvement in data quality since the previous performance audit.

Detailed guidance on how to conduct performance audits of air monitoring systems will be available from the Ministry.

Detailed guidance on how to conduct system audits of an air monitoring program will be available from the Ministry.

- D. Proponents must be able to provide proof of the integrity of the data acquisition system or method being used to collect the data from the air quality instrumentation.

Proponents must also provide upon request, proof of the security of the data base once collected. This includes data reduction or processing procedures (validating, rejecting, correcting), data storage and finally data reporting.

In the first instance, the use of a data logging device to automate data handling is no guarantee against data recording errors (i.e. bad data from good instruments!). There are two sources of error, (1) the output signal from the sensor and (2) the

errors in recording by the data logger and/or data transmission. Internal validity checks must be done and duly recorded to eliminate possible electronic interference from being converted to digital readout. For a system involving the use of telemetry, it is also necessary to include periodic validity checks for data transmission.

Data security is an important aspect to quality assurance.

Data security can best be achieved by restricting access to data files to authorized individuals. Any changes, corrections, deletions etc. must be justified, and duly and properly recorded in a "data logbook" along with the signature of the person making the change. The Ministry will maintain a list of names of those individuals authorized to make changes to data files.

Proponents must inform the Ministry of any changes in authorized personnel.

All air quality monitoring data must be archived by proponents. They must keep all air quality monitoring data for five years and any destruction, partial or complete, must have prior approval of the Ministry.

E. Proponents shall submit to the Ministry the following reports on QA/QC activities and air quality data at prescribed intervals as determined by the Ministry.

1. Quality assurance program plans

Comprehensive reports on the plans for the QA and QC activities for the CAP air monitoring program operated by the proponent. The objective, management structure, responsibilities and procedures for the total QA program will be included.

2. Performance and system audit reports

Reports summarizing the audit results and recommendation that the auditee has come forth.

3. Air quality assessment reports

At prescribed interval, the air monitoring data must be submitted with the quality assurance component data such as precision, accuracy using statistic, models and calculations as devised and recommended by the ministry.

As part of this report, the results of the data validation activities should also be summarized along with program downtime, for example, flagged questionable data, correction of anomalies and etc.

